To My Son, Lukas

# SELECTION OF THE MOST APPROPRIATE METHOD OF CONSTRUCTION

A thesis submitted in partial fulfilment of the requirements for the degree of Master of Engineering at the University of Canterbury, Christchurch, New Zealand.

by

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May 1990

# ACKNOWLEDGEMENTS

The work presented here was carried out in the Department of Civil Engineering, University of Canterbury, New Zealand under the overall guidance of its Head, Prof R. Park to whom I am very grateful.

I wish to express my most sincere gratitude to my supervisor Prof. David Scott (now in Queensland University of Technology, Brisbane, Australia) for his helpful guidance, invaluable suggestions and constant encouragement throughout the course of the study.

My gratitude also extends to Mr Derry Gordon for his assistance at various stages of the work. The advice and constant encouragement of Miss Marjorie Mujaji, the University Chaplains, Fathers Mike Doyle and John Airey, and all other friends is also gratefully acknowledged.

To my son Lukas, my parents and all other family members who supported and encouraged me in various ways I am truly grateful.

I am very thankful to Mr James Wokabi Murage for his invaluable efforts in collecting data for the study at short notice (with the help of a few others to whom I am also grateful) and for his constant encouragement, understanding and support in many ways especially during the study period.

I would also like to thank Mrs Louise Fitzgibbon for her assistance, helpful suggestions and cheerful patience in the typing and presentation of this manuscript.

Finally to my sponsors, the New Zealand Government through the Ministry of External Relations and Trade, I am truly grateful for providing the scholarship which made the study possible.

# ABSTRACT

A method of analysing the costs and durations of alternative methods of construction is presented as a possible way of solving some of the problems of the construction industry especially in developing countries. The method involved development and application of database computer programs. The type of data required, the possible sources and the effects of variation of the data are presented.

The use of the method is illustrated by its application to the earthworks and concreteworks associated with three projects: a gravel road project; a three storeyed building project; an oxidation ponds project. The construction data used has been obtained from Kenya.

The results of the study have shown how the costs and durations of a wide range of methods can be obtained from the readily available data. This helps project evaluators assess the relative merits of alternative construction methods with reasonable speed and accuracy thus facilitating consideration and adoption of more appropriate methods of construction for any given project.

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# CHAPTER 1

# INTRODUCTION

## 1.1 GENERAL

In recent years, increasing attention has been given to the problems and difficulties of construction in developing countries. Scarcity of resources and high unemployment are some of the factors that are very common in most developing countries.

These factors amongst others have prompted various bodies like the International Labour Organisation (ILO), International Bank of Reconstruction and Development (IBRD) and the World Bank to undertake studies and investigations into possibilities of adoption of the most appropriate techniques technically and economically that make best use of the available resources.

The fact that most construction activities can be carried out by many methods means that full (or satisfactory) employment of resources can be achieved by making best use of the locally available resources to suit economic circumstances.

Observations (ILO, 1979; Scott, 1986) have however shown that in terms of the total amount of construction work being done in most developing countries, it is only in a very small minority of projects that the methods adopted are different from those commonly used in developed industrialised countries. This is a result of a wide range of difficulties and restrictions. These include;

(a) Traditional tendencies of extreme reluctance to try new methods,

(b) Pressure of time which gives those concerned very little opportunity to assess and compare the merits of alternative methods of construction,

(c) Lack of information on type of data required, sources of data and method of analysing the data collected.

It is within the framework of these constraints that this study has been undertaken.

## 1.2 THE NEED FOR THE STUDY

To be able to make a rational choice of the best method of construction, all viable methods of construction for a particular project need to be investigated and the most suitable selected for given conditions.

One way to make this possible is to make available to the engineer (and all others involved in method selection) all the relevant information within the shortest possible time, thus enabling rapid assessment of the relative merits of alternative methods. The enormous increase in the availability of small computers and computer packages in recent years has great potential for making rapid progress in this regard by permitting instant access to such information. With such a facility, the adoption of methods most appropriate in developing countries is likely to be given consideration.

There is a great need therefore to investigate the times and costs associated with various alternative methods of construction hence the development of a simple and convenient method which can be used to determine the most suitable method of construction for given conditions would be of great value to engineers, contractors and others interested in best usage of the scarce resources.

## 1.3 OUTLINE OF THE PROPOSED STUDY

A review of the works done and studies carried out by various agencies and individuals on appropriate resource use is presented in Chapter 2 and the methods of construction currently used in Kenya are reviewed in Chapter 3. This is aimed at highlighting the traditional tendencies in construction methods and for emphasizing the need for investigation into possible ways of facilitating better resource usage.

An analysis of the costs of the input factors in construction (mainly labour and equipment) is presented in Chapter 4 and is aimed at giving some background information before the actual analysis of the input factors for the major works in the projects investigated.

The projects to be investigated and details of productivity of the resources required to carry out the works are presented in Chapter 5.

In Chapter 6 is presented the method developed in this study. This includes database computer programs, the type of input data required and the form of output. The method enables calculation and comparison of the times and costs of viable combinations of equipment and labour for the various works.

To demonstrate the working of the developed method, three projects are investigated; a gravel road project, a three storeyed building project and an oxidation ponds project. The major works in these projects are identified as either concreteworks or earthworks since these are the works that offer scope for application of alternative methods.

The results obtained from the analysis using data from Kenya are presented and discussed in Chapter 7. Also included in this chapter is a method of carrying out sensitivity analysis. This has been necessary because the construction industry is always characterised by an element of uncertainty in both cost and productivity estimates. This implies that there is need to consider the changes likely to be caused by such variations in evaluating alternative methods of construction.

A general procedure on how to apply the techniques developed in this study to investigate costs and durations of alternative methods of construction are presented in Chapter 8. The type of data required and the possible sources are suggested as well.

The conclusions arrived at from the study and recommendations for further work are presented in Chapter 9.

Though the data used is Kenyan based the method is applicable anywhere and it is hoped that this will be of great use not only to engineers and contractors but also to all others involved directly or indirectly with best resource use in the construction industry.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 GENERAL

Optimum use of the available resources in the construction industry in developing countries is one vital way of realising the objectives of these countries' wishes to improve the social-economic status of their populations. It is therefore urgent to examine carefully what type of technologies are most appropriate to meet those needs.

In view of this state of affairs, international agencies and organisations such as the International Labour Organisation (ILO), International Bank for Reconstruction and Development (IBRD) and the World Bank have been instrumental in sponsoring and/or undertaking research studies in various countries to examine the possibilities of adoption of the most appropriate techniques, technically and economically that make best use of the available resources.

These studies have been concentrated mainly in agriculture and civil engineering works which undoubtedly make use of the bulk of the available resources in developing countries. The basic aim in the comprehensive efforts of these organisations has been to distribute revenue equitably by generating more employment thus benefitting a wider section of the population.

Their work related to the appropriate use of the available resources (mainly unskilled labour which in most cases is in abundant supply) together with work done by others in similar or related fields is briefly reviewed.

## 2.2 ILO, IBRD AND WORLD BANK STUDIES

### 2.2.1 Labour/Capital Substitution in Road Construction

The ILO in particular has undertaken studies to investigate whether the use of labour intensive road construction in developing countries is technically and economically feasible. Alternative techniques have been identified for most of the operations in road construction.

One major study was of a road project in the Philippines (Lal, 1978), the Capas-Botolan Road Project. This was a two phased project aimed at developing and evaluating modified labour intensive techniques for the various tasks in road construction. In the first phase, traditional farm equipment was modified and used for the works. The second phase of the study was confined to the testing of the engineering estimates derived in the first phase by actual field experiments on the road project. In this phase, the World Bank compared phase one estimates of the productivities of men and machines with their own estimates derived in part from field studies in India and Indonesia. Thus, in the second phase it was possible to test the reliability not only of local engineering estimates but also of estimates based on productivity data from a different region and environment.

This study showed that it is possible to devise technically efficient labour intensive techniques at least for gravel road construction in the Philippines and that in road construction it is not possible to transpose productivity data valid for one environment and topography into another.

It is worth noting here that the ILO engineers' productivity estimates and the revised productivity estimates for this project by labour intensive, capital intensive and modified labour intensive methods did not include site overheads since these were assumed to be of the same order whatever method was used. The assumption was that the cost of extra facilities required for large labour forces would be balanced by the facilities required for the maintenance and repair of equipment. As such overheads would amount to about 10 per cent of the total project cost hence the effect of any minor differences become minimal. While this may be valid for a particular project, a more detailed analysis of the overhead costs should be carried out especially because maintenance and repair of equipment in developing countries and importing of skilled labour usually involves huge expenditure of the scarce foreign exchange.

Other studies were carried out in Pakistan (ILO, 1977) on the Indus Super Highway. This study was especially significant since it was the first time that such a large scale project as a major highway was involved. The objective was to get the most appropriate method of construction. Manpower surveys were carried out to provide overall data on the potential labour supply.

From the studies, it was concluded that;

(i) Labour intensive methods are technically feasible and economically viable particularly for earthworks.

(ii) It is possible to integrate labour intensive and capital intensive methods in large projects by careful planning and organisation.

(iii) Integration of labour intensive methods in highway construction when well planned, does not affect the project duration or the standard of the work.

Studies have been carried out by Scott Wilson Kirkpatrick and Partners (1974) in Kenya on a Rural Access Road Programme for the various donor agencies which included the World Bank, governments of the United Kingdom, the Netherlands, U.S.A, Denmark and Norway. The programme was aimed at providing 14,000 km of all weather rural, low volume roads by appropriate labour based methods employing a peak labour of 20,000 workers. There was a considerable technical and managerial input with a number of experts in work measurement, organisation and methods, labour supply and tools supply.

Over 2,300 km of road has been completed in the programme and about 1,500 km are being added every year.

The labour is recruited from the surrounding villages. No transport is provided to site so that the area of recruitment is controlled by the maximum distance that a labourer will walk. Wage rate is about US $1.0/day.

Taskwork incentive where the labourer goes home after finishing a given set task is used on all possible activities and has resulted in increased labour productivities.

### 2.2.2 Labour/Capital Substitution in Other Works

Scott Wilson Kirkpatrick and Partners (1977) carried out studies for the setting up and running of a Labour Intensive Construction Unit in 1977 in Lesotho with funding from IBRD and Lesotho government.

The object of setting up the unit was to build an organisation that would carry out civil engineering work by labour intensive methods and to compare the results with similar works by capital intensive methods.

As in the Kenya programme, the labour force was recruited from the villages surrounding the project. Taskwork incentive was used wherever possible.

Works carried out in this programme include:

- construction, rehabilitation, regravelling and maintenance of gravel roads;
- rehabilitation of 23 gravel (mountain) airstrips and maintenance of fifteen of them;
- construction of terraces, waterways, donga control and tree planting for agricultural conservation works;
- construction of earthworks for fish ponds;
- experimental work on lime stabilisation on bases and bituminous dressings on bituminous roads.

For most of these projects it was found that even with the relatively high wage rates in Lesotho (US $ 3.0/day), labour based methods are competitive with or cheaper than equipment based methods. 150 km of gravelled secondary roads have been constructed for the Ministry of Works by the Labour Camp Unit using labour based methods which have been found to be cheaper than equipment based methods.

Comparison made between similar labour and equipment based projects showed that in road construction, five times as many jobs are produced per unit of investment by using labour based methods. In agricultural conservation works, ten times as many jobs are produced using labour based methods.

Other projects where appropriate methods of construction have been studied (SWK, 1976) are Sategui-Deressia Irrigation project in Chad, road project in Malawi and Feeder roads in Benin among others. In all these studies it has been established that labour based methods can be technically and economically feasible with proper management.

## 2.3 LABOUR/CAPITAL SUBSTITUTION-CRITICAL PATH ANALYSIS

Confining his studies mainly to earthworks and some concreting, Sheikh (1977) examined the feasibility of substituting labour intensive methods for capital intensive ones. This he did by using the concept of critical path analysis and adopting an intermediate approach in which critical activities were carried out by mechanical means and all others by labour intensive methods. An irrigation project of the Royal Irrigation Department of Thailand was used to illustrate the working of the model.

Productivity data used in this project was adopted from ILO sources based on road construction elsewhere. Skilled and unskilled labour rates were also based on the figures modified to cover inflation. Using this, Sheikh made a time cost comparison to determine which of the capital, labour and intermediate techniques was most suitable for Thailand.

The studies showed that it is possible to integrate capital intensive and labour intensive methods in earthworks by a process of relaxation. This method was found to be competitive in terms of cost and time and that it is possible to incorporate in the project desired characteristics such as low cost, low foreign exchange expenditure, short project duration and employment creation.

One drawback in Sheikh's method however was the assumption that productivity data obtained elsewhere is also applicable to Thailand. Some differences actually exist due to environmental and topographical variations.

## 2.4 ALTERNATIVE METHODS IN BUILDING PROJECTS

Munir (1978) carried out work on substitution of labour intensive for capital intensive techniques in building construction.

The study was aimed at comparing the costs of alternative construction methods using 'The New Head Office of The Bank of Thailand'. He confined his studies mainly to formwork and concreting where he found some reasonable scope for labour substitution.

The productivity data for these activities was found by carrying out work study using time-lapse photography. The material cost was based on the unit market rate and for equipment cost, an hourly rate for owning and operating each unit was estimated. Labour costs were based on completion time and site overheads.

The labour based method was found to cost least and it generated maximum employment for unskilled labour and had little effect on project duration.

The study also proposed that for concreting at higher elevations, a labour intensive approach integrating a mechanical hoist works out cheaper than using a tower crane.

Some drawbacks observed in this study were that the costs were based on the market rate which may not necessarily reflect the true values, besides, market rates tend to fluctuate considerably, depending on the market considered. The utility factor was overlooked in deriving labour costs and it is rare that an ideal situation (where the entire labour force is productive throughout) arises in the construction industry.

Sridurangkatum (1978) carried out work to determine the most suitable construction method for low income multi-family houses in Bangkok, Thailand. His work involved a comparative study of different construction methods which could be used by local construction companies. Four types of designs were investigated. These were, the design that was currently in use, concrete block bearing walls, prefabricated beam and columns and prefabricated panels. Work was carried out in three stages. In the first stage the ability of local building contractors to use the construction methods being investigated was assessed. The second stage involved engineering analysis and structural design for each method. The final stage was the economic analysis of each method.

His results showed that construction using the prefabricated panel method was the cheapest followed by the prefabricated beam and column and the concrete block bearing wall and traditional methods.

Sensitivity analysis of the results calculated by varying all unit costs and production rates by + or - 25% showed that material cost was the most sensitive of the various costs of the considered methods in the building works considered.

Krishnan (1981) carried out further studies on appropriate construction methods and he came up with an analytical method that can be used to analyse any construction project to determine the method most appropriate to a country in terms of total project cost, duration and resource use. The method developed can be used, especially for countries with a labour surplus, to examine the economic and social desirability of construction methods generating maximum employment.

Several alternative methods of construction were examined for three projects in Fiji; a bridge, a multistorey building and an irrigation canal. The analysis incorporated methods that were current in Fiji and used the local rates for wages, equipment and material costs. The productivity data used in the study was adopted mainly from ILO studies.

Results indicated that for projects not requiring large amounts of concrete at a time, concreting by labour intensive methods is more economical and more appropriate in terms of employment generation than using crane and skip. For a cast in situ reinforced concrete building in Fiji, it was most economical costwise and timewise to place concrete by pumping while earthworks are best carried out by mechanical means for the projects considered.

## 2.5 BUILDING CONTRACTORS IN KENYA

When looking at optimum utilisation of the scarce resources in the building industry, it is worth looking at the position of the contractors in the developing countries since they have a very big part to play in any resource utilization programme.

The Intermediate Technology Development Group (ITDG, 1973) has carried out research work to examine the practices, problems and needs of the African building contractors in Kenya with a particular emphasis on the difficulties faced by the small entrepreneurs.

From the studies it was found that there are three types of building contractors in Kenya. These are ;

(i) <u>The one man business</u>

This proved to be the most prevalent as well as the most successful and lasting form of organisation. It was however found to be characterised by some problems. These are; personal misfortune which may lead to partial or total collapse of the business, high risk factor, shortage of capital, dependence on hired staff, employment of specialists usually not done satisfactorily, lack of financial skills, lack of dedication to industry always ready to withdraw if the economic conditions deteriorate, lack of managerial skills and poor general organisation in most cases.

(ii) The partnership

Two or more individuals own and run the company. While this kind of firm overcomes some of the problems the one man business encounters, there are two main problems. These are; Incompetence of one or all the partners either in the technical or managerial aspects of the contractors' operations and the problem of trust amongst the owners.

(iii) The limited company

Limited companies were found to be quite few and the few that were there were found to have a tendency to over-expand operations leading to inefficient performance in some cases.

Other studies have been carried out by ILO (Edmonds, 1977) who mainly concentrated on the restraints to the development and growth of small contractors in Kenya. A survey of 97 contractors, representing 7% of the total number of small firms registered in Kenya then, was conducted to collect data on the following aspects of small firms:-

(i) The market
(ii) Employment
(iii) Finance
(iv) The use of plant and labour
(v) General problems

The survey showed that small contractors in developing countries are subject to many economic constraints. The study showed that the main problem faced by small contractors in Kenya were;

(i) Fixed assets were a prerequisite of being awarded jobs.
(ii) Lack of continuity of work prevented them from maintaining a reliable labour force on permanent basis to carry out work effectively, thereby reducing their chances of obtaining jobs.

(iii) Lack of sufficient profit prohibited them from reinvesting and expanding their small firms.

(iv) The smaller the firm, the more it relied on casual labour.

(v) Regular cash outflow coupled with irregular cash inflow exhausted the firms' resources, thus limiting the reserves for fixed assets.

(vi) Small contractors could not afford to buy plant and equipment and so had to rely on inefficient technology and low productivity.

The survey isolated the provision of continuity of work as the major difficulty faced by the small contractors. To generate productive employment and domestic industrial growth, the study proposed that closer attention should be paid by local contractors to viable alternative capital saving techniques in construction and that a need for training on the use of such techniques existed.

## 2.6 RESOURCE MANAGEMENT IN CONSTRUCTION

Resource planning and management is one of the most important ingredients for effective resource utilization in today's construction industry. In order to control costs, equipment and labour should be utilised in the most efficient way possible. This can be achieved by minimizing total cost of leased resources under the constraint of labour force.

Perera (1983) carried out studies on resource sharing in construction and developed a method that employs resource hour units to allocate resources precisely to requirements. The method uses linear programming to determine the maximum rate of construction and the resource requirements in various construction activities. Sharing resources which are available in limited quantities and balanced trades are all catered for in the developed method. The economics of using additional resources, working overtime and the optimal usage of all resources are considered. Four activities in a housing unit construction project are examined to show the working of the method.

Further work in this field was done by Karaa and Nasr (1986) who developed a mixed integer linear programming method for the management of resources throughout the life of a project. Based on the Critical Path

Method time analysis, the method derives the schedule for equipment rentals and transient resources, as well as the utilisation scheme for owned equipment and other resources given a certain level of resources available. The model can be used as an estimating tool for multiproject resource planning and sharing, and as a means to implement the most efficient utilisation of resources throughout the project life.

The major limitations of these two methods are issues of project dimension. As the project increases in complexity, the number of integer variables becomes too large to handle even with existing computer software capabilities. This necessitates the need for a simpler method of approach to the problem.

## 2.7 A SUMMARY OF THE REVIEW

The problems and difficulties of construction in developing countries have received a great deal of attention in recent years by various bodies and individuals. Alternative methods of construction have been investigated to find the most appropriate ones as a major step towards optimising use of the scarce resources in construction.

From the studies, labour based methods where appropriate and when properly managed, have been found to be both technically and economically feasible for the jobs cited in the review.

The position and problems of small contractors in developing countries have been reviewed to highlight the need for investigation of the best ways of utilising the scarce resources.

For the works analysed, the various construction activities are carried out by specified methods and the associated costs and times compared to select the best method. Comparing costs and times associated with a few specified methods, however, limits the scope of optimising resource use especially in view of the fact that most construction activities can be effectively done in many ways.

A variety of methods for utilising the resources most efficiently have been developed. While quite convenient for small projects, the use of these methods becomes limited for large projects.

The aim of the construction industry in developing countries is to develop in a way that enables all those concerned to make a rational choice of the full range of alternative methods available and at the same time be able to take into account the current local information on costs and productivity. There is need therefore to investigate the times and costs associated with the various alternative methods hence the development of a simple and convenient method which can be used to determine the most suitable method of construction would be of great value to engineers, contractors and all others interested in optimum utilisation of the scarce resources.

## 2.8 THE PROPOSED RESEARCH

From all the studies carried out on the various methods of construction, there is need to examine the technical and economic viability of using semi-mechanised methods e.g. agricultural tractors modified to perform earthworks operations. Alongside this, there is need to devise a method that is easy to use and which can examine the viable resource combinations in construction while taking into account the current local information on costs, productivities and availability of resources.

# CHAPTER 3

# CONSTRUCTION TECHNIQUES CURRENTLY USED IN KENYA

## 3.1 GENERAL

In Kenya, like in most developing countries, though there is relatively abundant and cheap labour supply, construction work is mainly carried out by capital intensive labour saving technologies adapted from the developed countries.

The use of alternative technologies more suitable to the prevailing conditions in Kenya are usually not given much attention mainly because of the belief that labour based technologies are inferior in terms of quality and productivity. In addition to this negative attitude some institutional constraints have been found (ILO,1979) to be prevalent. These include;

(i) The serious shortage of local technicians which is made worse by the fact that the educational system and syllabii have been taken over from the developed world hence the few technicians available are mainly conversant with capital intensive technology.

(ii) The administrative systems e.g. personnel and procurement in the construction industry are geared to the use of capital intensive methods.

(iii) Research on the improvement of traditional technologies has hardly begun and organisation and management techniques have not been adapted to the use of labour intensive methods.

(iv) Financial assistance to development programmes is often tied to the purchase of foreign technology.

Nevertheless, there are some construction activities that are usually carried out manually, for example, excavation for simple foundation systems.

Various methods currently used for earthworks and concrete works are reviewed in the following sections.

## 3.2 CONCRETE WORKS

Concrete works comprises of the activities of mixing, hauling and placing and vibrating. The methods used for each of these activities are outlined.

### 3.2.1 Mixing

Concrete is normally mixed by machine though hand mixing is also used especially where the quantity of concrete required is minimal.

### 3.2.2 Hauling and Placing

Five methods for transporting and placing concrete are used in Kenya. The method used for a particular job depends on the job characteristics, the equipment available and on the capability of the contractor. The methods are outlined below.

#### 3.2.2.1 Concreting with crane and skip

This method is usually used where concrete has to be placed at high levels or where site conditions are such that there is practically no room for maneuvre for other methods of hauling. The rate of placing of concrete by this method is governed by the height and distance of the placing point in relation to the mixing place, the rate of discharge from the skip (which depends on the configuration and position of the particular element being concreted), the capacity of the skip and the capacity of the mixer.

#### 3.2.2.2 Concreting with mechanical pump

The output from a mechanical pump system is probably the highest of all the methods of hauling and placing of concrete and is usually used on jobs that require large volumes of concrete at a time,for example concrete works in dam constructions and waterworks channels. The rate of pumping depends on the vertical and horizontal distances to the desired location, concrete slump and the line pressure. A batch mixing plant is usually used for mixing to cope with the very large amounts of concrete for efficient use of the pumps.

3.2.2.3 Concreting with wheelbarrows

Hauling and placing with wheelbarrows is a very commonly used method especially where small to moderate volumes of concrete are required at a time. The number of wheelbarrows employed depend on the size of the job and the capacity of mixer.

To place concrete at locations of upto three floors above the ground level, cheap wooden ramps and temporary works are erected to facilitate the hauling and placing with wheelbarrows.

3.2.2.4 Concreting with hand (or head) pans

Hand pans are locally manufactured containers and are extensively used especially where not very large quantities of concrete are required at a time. The method involves filling of the pans at the mixing place and passing them on to the placing point by men or women who are queued up. The empty pans are then returned for filling through a different route.

For placing of concrete at locations higher than ground level, some temporary steps are constructed and on each step there are workers to pass on to the next higher step. Up to four floor heights can be concreted by this method.

3.2.2.5 Concreting with rail carts

Use of rail carts for hauling is one of the most uncommon methods being mainly confined to large works like in water works channels and tunnel construction.

3.2.3 Vibrating

Vibrating of concrete is usually done by using poker vibrators for most of the works.

## 3.3 EARTHWORKS

The major activities comprising earthworks are excavation, loading and hauling, unloading, spreading and compacting. The method used for each of these activities are outlined;

3.3.1 Excavation

The type of equipment or method used for excavation depends on job characteristics and/or the capabilities of the contractor. The most commonly used methods are by;

3.3.1.1 Hoe, Shovel, Pick or Crowbar

These are hand operated simple tools (which are mostly locally manufactured) and are most commonly used in foundation works especially in building sites. These tools have also been successfully used in the labour intensive rural access road programme (de Veen, 1980).

3.3.1.2 Hand drill/blast

Excavation by using hand drill and blast is usually confined to rocky sites where other methods of excavation cannot be employed.

3.3.1.3 Agricultural Tractors

Use of agricultural tractors fitted with blades for excavation works is limited to only a few areas where tractors are used for farm activities and where the terraine allows their convenient use.

3.3.1.4 Bulldozer, Excavator, Scraper

The use of these machines for excavation is widespread especially in major roadworks and other large excavation works. These heavy machines are also used in building site excavation works.

3.3.2 Loading, Hauling and Unloading

The mode of hauling usually depends largely on the volume of material, type of material, the weather, the haul route and the haul distance among other factors. Any one grouping of the equipment listed below is used.

3.3.2.1 Hoe/headbasket

Loading is done by use of the hoe and hauling and unloading by use of headbasket. This method however,is not very commonly used except in a few scattered areas on small to medium size jobs.

3.3.2.2 Shovel/Wheelbarrow

Loading with shovels and hauling and unloading with wheelbarrows is one of the most commonly used methods especially for small to medium sized jobs and where the haul distance does not exceed 150m.

3.3.2.3 Shovel/Animal Cart

The use of animal carts for hauling is confined to very few areas where animals (donkeys and oxen) are used for farm activities as well.

3.3.2.4 Shovel/Flatbed Truck

Loading and unloading with shovels and hauling with flatbed truck is common where the haul distance exceeds 500m and where the haul route is adequate.

3.3.2.5 Bulldozer with Dumptruck or Flatbed truck; Scrapers

These equipment are very commonly used for quite a variety of works (extending from fairly small building excavation works to major earthworks for dams and roads). The choice of any one particular combination of equipment depends on haul distance among other factors.

3.3.3 Spreading

The method of spreading usually depends on the method of hauling used. However, handtools, graders and dozers are commonly used for most of the works.

3.3.4 Compacting

Method of compacting used usually depends on the job specifications. Use is made of;

(a) Hand tampers which are metallic or wooden hand tools and are mainly used on small jobs and confined spaces such as foundation trenches.

(b) Hand-propelled mechanical rollers which are of various types and their use is mainly limited to small to moderate jobs.

(c) Tractor-towed Rollers and Smooth-Wheeled Self-Propelled Rollers are the more common types of equipment used for compacting most of the earthworks.

## 3.4 FACTORS THAT AFFECT THE CHOICE OF METHOD

There are various factors that affect the choice of method of construction in addition to the constraints mentioned in section 3.1. The factors are given below (ILO, 1979; Scott, 1986);

### 3.4.1 Design

In most cases, designs are geared towards equipment based or other intermediate methods.

### 3.4.2 Technical feasibility and quality

The achievement of high-quality standards at times dictate the use of mechanical equipment only, such as compaction of fill material, asphalt paving for fast highways and mixing of high quality structural concrete.

Some operations however, can only be done by specific methods e.g. deep pile driving and excavating underwater which are solely capital intensive and stone pitching, masonry and brick walling which are exclusively labour intensive.

### 3.4.3 Costs

Where a job can be done by several methods, i.e. Capital Intensive, Labour Intensive or a combination of both, then it is usually necessary to ascertain which is economically and socially most advantageous to the country.

### 3.4.4 Time Pressure

Designers and contractors are often under a great deal of pressure to complete the work within the shortest possible time. This gives them very little opportunity to assess and compare the merits of the alternative methods of construction and, consequently, they are naturally inclined to opt for known and tested methods.

### 3.4.5 Scale

The size of a project dictates the method used for construction. On confined sites for example, there is a limit to the maximum amount of labour (or units of equipment) that can be efficiently employed. However, on unconstrained sites such as roads, there is greater opportunity of employing various techniques.

3.4.6 Location

For projects that are small and scattered, the use of manual labour is often more effective, more economical and sometimes the only feasible method.

There are other situations however, when the work site is away from the main source of labour such that if labour based methods are used, it would be necessary to provide ancillary services such as housing, medical care, transport and food supplies and this may sometimes put the equipment intensive methods, if feasible, in a favourable position.

3.4.7 Resources

The availability of resources in terms of labour, plant, material, management and supervisory skills make a significant effect on the choice of method of construction.

3.4.8 Traditional Tendencies

In the construction industry, there is extreme reluctance to try new methods if proven methods can be used. The methods of construction which most engineers know best are those currently in use in industrialised countries where machines are invariably used to minimise high labour costs.

Because of this reluctance to change from familiar machine oriented methods, labour based methods of construction are at a serious disadvantage as few engineers are able to gain expertise in their use.

3.4.9 Lack of Information

The information needed to make a cost and time comparison of the alternative methods is not available to the engineers responsible for design and construction in many instances. Information on labour based methods is lacking unlike the production and costs of equipment which is readily available.

3.4.10 Others

Foreign aid (which sometimes is tied with conditions that only favour particular methods), political effects (which may lead to policy decisions that have various effects on who executes the project or how the work is going to be done) and bidding methods (where foreign contractors' artificially low bids for construction work can be attractive to the client hence leading to opting particular methods of construction) are some of other factors that affect the choice of method.

## 3.5 SUMMARY

A review of the current methods of construction in Kenya, especially for earthworks and concreting has been done with an aim of highlighting the need for optimising use of the scarce resources. The various factors and constraints in the choice of method of construction have also been reviewed.

# CHAPTER 4

# COST ANALYSIS FOR THE INPUT FACTORS

## 4.1 GENERAL

Where it is technically feasible to carry out construction activities by several alternative methods, then it becomes necessary to ascertain which is economically and socially most desirable.

Resources required for the construction of a project fall into one or other of the following groups (ILO, 1979);

(i) Labour; which includes
- unskilled labour
- skilled labour

(ii) Simple equipment; which includes
- hand tools and containers
- simple non-powered devices

(iii) Capital equipment; which includes
- mechanical equipment (non-powered)
- mechanical equipment (powered)

(iv) Material; which includes
- local material
- imported material

(v) Management; which includes
- managerial staff
- supervisory staff
- technical staff

(vi) Service; which includes
- service facilities.

For purposes of this study, more emphasis will be laid on labour and equipment (both simple and capital) because in the use of these resources, unlike in materials, there is considerable opportunity for choosing alternative methods for combining the resources for efficient usage. However, all construction costs as classified below are reviewed.

To analyse construction costs methodically, it is essential that the basic elements that comprise the bulk of the costs be identified.

Costs of work may be classified as follows;

(i) Material costs

(ii) Labour costs

(iii) Equipment costs

(iv) Overhead costs

(v) Profit

Specific items of work may sometimes be classified in more than one of these classifications and other items may not always clearly belong to any one of them. However, the primary value of these classifications is that they help one examine and analyse construction costs.

## 4.2 MATERIAL COSTS

The price of materials is subject to supply and demand and is affected by such factors as quality, quantity, time, place, buyer and seller. The higher the quality, the higher the price to be paid and the larger the quantity purchased, the lower the price.

Time affects the price in that the market keeps changing with fluctuating supply, demand and other economic factors while place and location affects the price through the means and distance of delivery and the accessibility of the site.

Other costs that may be associated with materials include storage costs, taxes, damage and loss, wastage, insurance protection and security.

The projects investigated in this study do not relate to any particular site and the aim is to investigate the various alternative methods of carrying out construction activities hence material costs will be considered constant for all projects since they are independent of method.

## 4.3 LABOUR COSTS

Labour costs are determined by two factors;

(i) Labour Rates

The hourly rate of employing workers based on the total labour costs divided by the number of hours worked is the labour rate.

(ii) Productivity

This is the amount of work done by one worker in the specific period of time paid for.

### 4.3.1 Labour rates

Labour rates include all labour costs, both direct and indirect. Direct labour costs are wages and other payments made directly to the employee. Indirect labour costs are other payments made by the employer on the employees' behalf, and these include fringe benefits (e.g. paid vacations, pension fund payments, group insurance premiums etc.) and statutory payments (e.g. contributions to the national social security fund). The wage rate is the direct cost per hour. The labour rate is the total of direct and indirect costs per hour.

The basic minimum wage rates used for this study are obtained from the Kenya Association of Building and Civil Engineering contractors. A rate of 25% of the direct labour cost is added (Collier, 1974) to include the indirect labour costs.

### 4.3.2 Productivity

Productivity is one major aspect of all costs in construction. There are however, innumerable and diverse variables that affect productivity and this probably explains why not much has been done in this subject.

ILO and other agencies have however, carried out some studies in Kenya and other developing countries especially on roadworks and the productivity rates from these studies have been adapted for this study.

For purposes of this investigation, workers are classified into two groups; skilled labour and unskilled labour. Skilled labour includes general tradesmen (e.g. carpenters, masons etc), plant operators, drivers, mechanics, foremen etc. The basic wage rates for the various skills are different. Unskilled labour includes general labourers who have no special skill. The basic wage rate is taken as uniform for all categorised under unskilled labour in this study.

## 4.4 PLANT AND EQUIPMENT COSTS

Plant and equipment can be either owned or rented. However, in estimating plant and equipment costs, it makes no essential difference whether plant is owned or rented because in either case the estimate should allow for all the plant and equipment costs at realistic rental rates. Hence, for this study, plant and equipment rates are considered the same whether rented or owned.

Plant and equipment costs fall into two categories (Collier,1974);

(i) Owning costs (the cost of owning plant and equipment)

(ii) Operating costs (the cost of using the plant and equipment over and above the owning costs)

### 4.4.1 Owning Costs

Owning costs include a charge for:

(i) Investment:- Costs arising from investment include interest on investment, insurances and taxes on plant and equipment and storage costs.

(ii) Maintenance:- Maintenance costs are a result of major repairs and replacement of parts and they vary with the type of plant and equipment and type of work done.

(iii) Depreciation:- Depreciation is usually the biggest single cost and results from wear and tear of the plant.

### 4.4.2 Operating Costs

Operating costs include a charge for;

(i) Fuel (including lubricants and additives)

(ii) Running repairs (includes minor repairs and replacement of small parts)

(iii) Transportation (includes transporting to and from site, setting up and dismantling)

(iv) Operator (includes wages and fringe benefits)

Plant and equipment hourly rental rates used for the projects investigated include all owning costs and operating costs and have been obtained from Kenya.

4.4.3 Simple Equipment Cost

Enterkin and Reynold (1978) gives a method of calculating costs which allows a percentage of the labour cost (2.5% to 1.0% of labour cost) to cover the cost of simple equipment (also referred to as hand tools). For this study 2.5% of the unskilled labour cost will be taken as the simple equipment cost.

4.4.4 Overhead Costs

Overhead costs are construction costs that cannot be attributed to any specific item of work. These costs are normally classified in one of the two classifications given below;

(i) Job Overhead Costs
(ii) Operating Overhead Costs

4.4.4.1 Job Overhead Costs

Job overhead costs are costs that can be attributed to a specific job site because they arise only from that particular job. Although the costs are of a general nature, they may include a fraction of material costs, labour costs and/or plant and equipment costs. In general, job overhead costs are estimated as a percentage of the total cost of the project. For the projects analysed, a job overhead cost of 7.5% (Collier, 1974) is added to the unit rates of the input factors to account for overhead costs.

4.4.4.2 Operating Overhead Costs

Operating overhead costs are those costs that cannot be attributed to any particular job. These costs may include:

(i) Management and staff (their direct and indirect costs)
(ii) Business offices (rent, furniture, supplies and stores)
(iii) Communications (e.g. telephone and postage costs)

A rate of 7.5% of the unit rates is added to cover operating overhead costs (Collier, 1974).

Hence total overhead costs considered in this study sum up to 15% of the unit costs of the factor inputs.

## 4.5 PROFIT

Profit is the difference between total income and total expenditure. The amount of profit usually depends on the size of the business, the turnover, market conditions and the nature and type of work amongst other considerations.

Most builders allow for 10% to 12% of total costs of the project for profits. 10% of the total cost is adapted in this study to allow for profit.

## 4.6 ACCOUNTING OR SHADOW COSTS

### 4.6.1 General

This study is aimed at investigating the various methods that can be used to carry out construction activities by considering various combinations of resources. To determine whether the alternative methods are socially desirable, it is essential that the costs and benefits of these methods be evaluated using shadow costs.

The shadow price for a factor of production is defined as the opportunity cost (or output forgone) or the social cost of using that factor.

When a worker is drawn from one occupation **i** with wage **Wi** to another occupation **j** by the offer of employment at wage **Wj**, the country experiences changes in the economy in addition to the wage paid to the worker. The social costs of employing the worker are (Scott, McArthur, Newbery, 1976):

(i) The social cost of employing him had he been employed at the same conditions as in occupation **i**;

(ii) The social cost of providing the resources needed to meet the extra expenditure resulting from any excess of **Wj** over **Wi**, and from any bidding up of Wj as a result of increased employment in **j**;

(iii) The social benefit accruing to the worker and others resulting from any excess of $Wj$ over $Wi$, from any differences in the conditions of work between i and j, and from any bidding up of $Wj$ as a result of increased employment in j;

(iv) The external cost (or benefit) of employing one more man in occupation j e.g. provision of additional roads, sewerage facilities, schools etc. (The external cost or benefit per worker is assumed negligible and will be taken as zero in this estimate).

Each of the above social cost components must be expressed in terms of a numeraire (or yardstick) which is the foreign exchange equivalent in the hands of the government.

An example of a general method of estimating the shadow wage using the Little and Mirrlees (1974) method applied in Kenya is shown below (where Kp is an abbreviation for Kenya pound).

Consider that a worker earning Kp610.00 per year in the rural area gets employed in the urban area and starts earning Kp1200.00 per year. The social cost of employing him is estimated as shown below (Scott, MacArthur, Newbery, 1976);

<u>Step 1</u> Estimate the value of output forgone i.e. the shadow wage in the former employment. The market wage at the previous employment (Kp610.00) is used here.

<u>Step 2</u> Estimate the resource cost of the worker drawn from one occupation to another. There are five steps in the calculation:

(i) Estimate the worker's earnings in each of the two occupations;

(ii) Deduct direct taxes to obtain disposable income;

(iii) Divide the remainder (disposable income) between amounts accruing to rural households and to urban households;

(iv) Divide the figures obtained in (iii) in turn into extra savings and extra consumption;

(v) Convert each component into foreign exchange equivalent costs.

For the worker under consideration, the resource cost is as given in Table 4.1.

Table 4.1 Resource Cost Analysis

| | Previous Rural job (Kp) | Previous Urban job (Kp) |
|---|---|---|
| Earnings | 610.00 | 1200.00 |
| Direct Tax | 0.00 | 40.00 |
| Total disposable income | 610.00 | 1160.00 |
| Disposable income accruing to:- | | |
| Rural: savings | 50.00 | 20.00 |
| consumption | 560.00 | 130.00 |
| Urban: savings | 0.00 | 100.00 |
| consumption | 0.00 | 910.00 |
| Resource cost in foreign exchange equivalent | 366.00 | 720.00 |
| (Assume a conversion factor of 0.6) | | |

The resource cost of drawing the worker from his rural job to the new urban job is the difference in the resource cost in foreign exchange equivalent, i.e Kp720.00 - Kp366.00 = Kp354.00. In the case of a worker who was previously unemployed, the resource cost of his new employment would be Kp720.00 - Kp0.00 = Kp720.00.

Step 3 Estimate of the benefits accruing from the extra wage paid to the worker and others from the extra income.

| | |
|---|---|
| Total increase in disposable income: (Kp1160.00 - Kp610.00) | 550.00 |
| Increase in disposable income accruing to: | |
| the worker's relatives | 150.00 |
| the worker and his family | 400.00 |
| Compensation for change in conditions of work | 0.00 |
| Net gain of worker and his family | 400.00 |
| Total net gain in terms of numeraire | 240.00 |

Step 4  Determine the social cost of labour obtained by bidding up wages.

| | | |
|---|---|---|
| Value of output forgone (step 1) | = | Kp610.00 |
| Resource cost of new employment (step 2) | = | Kp354.00 |
| Benefit to worker and others from new job (step 3) | = | Kp240.00 |

Therefore, the shadow wage of his new employment is Kp610.00 + Kp354.00 - Kp240.00 = Kp724.00, which is 0.60 times his new market wage.

4.6.2 Shadow cost estimates

4.6.2.1 Material costs

Material costs for this study are assumed constant for all the alternative methods of construction considered for the various projects. The shadow cost of materials is considered equal to the market cost.

4.6.2.2 Unskilled labour cost

In Kenya, there is sufficient supply of unskilled labour at present in both the urban and rural set-up. From studies carried out in Kenya on Project Appraisal (Scott, McArthur, Newbery, 1976), The shadow cost of unskilled labour was found to range in most cases from 0.70 to 1.0.

For this study, the effect of four alternative estimates of the shadow wage rate on the cost of various methods of construction is investigated. The four alternative estimates of the shadow wage rate (SWR) are:

(i) SWR = 1.5 x Market Rate
(ii) SWR = 1.1 x Market Rate
(iii) SWR = 1.0 x Market Rate
(iv) SWR = 0.8 x Market Rate

4.6.2.3 Skilled Labour Cost

An accounting ratio of 0.8 for skilled labour was found to be appropriate (Scott, McArthur, Newbery, 1976). However, for all the alternative methods of construction considered, four alternative estimates of shadow wage rate (SWR) are used. These are:

(i) SWR = 1.5 x Market Rate

(ii) SWR = 1.1 x Market Rate

(iii) SWR = 1.0 x Market Rate

(iv) SWR = 0.8 x Market Rate

4.6.2.4 Plant and Equipment Cost

Most plant and equipment used in Kenya are imported, at the cost of valuable foreign exchange. A fairly good number of mechanics, operators and other specialised craftsmen are permanently employed to operate, repair and maintain these machines.

The appropriate costs of plant and equipment need to be based on the shadow rental rate which is derived from the border price of the machines plus the accounting cost of port handling and other payments at accounting prices. Besides, the operational cost also needs to be estimated at accounting prices. Four alternative shadow rental rates (SRR) are assumed, based on studies in Kenya (Scott, McArthur, Newbery, 1976) and labour/capital substitution in road construction in the Philippines (Lal, 1978). These are:-

(i) SRR = 2.0 x Market Rental Rate (M)

(ii) SRR = 1.5 x M

(iii) SRR = 1.0 x M

(iv) SRR = 0.8 x M

## 4.7 SUMMARY

The various resources required for construction activities and their respective costs have generally been reviewed. This cost analysis is meant to give a basis for the individual project costing to be done at a later chapter.

For purposes of investigating the costs of various methods of carrying out construction activities, labour and equipment costs are considered the only variable resources since materials remain the same whatever method of construction is used.

Various accounting ratios have been established to be used for a more realistic comparison of costs at both market and shadow costs for the alternative methods of construction considered.

The accounting ratios used for this study are:

Unskilled Labour: 1.5, 1.1, 1.0, 0.8
Skilled Labour: 1.5, 1.1, 1.0, 0.8
Plant and Equipment: 2.0, 1.5, 1.0, 0.8

# CHAPTER 5

# THE PROJECTS INVESTIGATED AND THE RESOURCES REQUIRED

## 5.1 GENERAL

To be able to compare the suitability of alternative methods of construction, there is need to look at the types of labour and equipment resources that each method requires.

In this study, it is assumed that the quality of output of all projects is the same whatever method of construction is used.

A summary of the projects to be investigated is given together with various equipment and labour resource options for the major tasks.

## 5.2 THE PROJECTS INVESTIGATED

(i) A Gravel Road Project
(ii) A Three Storeyed Building Project
(iii) An Oxidation Ponds Project

### 5.2.1 The Gravel Road Project

#### 5.2.1.1 General

The road project is an average gravel road assumed to be 3 Km long and with a formation width of 6.0 m. The terrain is taken to be generally flat but where there are slopes then they do not exceed 5%. The soil over the stretch of the road is assumed to be a fairly uniform cohesive type. More than 30 vehicles per day are expected to use the road and it is also assumed that the road will be constructed such that it can be upgraded later if so desired.

#### 5.2.1.2 The Works

The major works for the gravel road project are earthworks and are outlined below:

(i) Clearing medium bush and grubbing (18000 sq.m)

(ii) Excavating (cut) and hauling 2500 cu.m of soil to use as fill on section of road 200 m away (later on referred to as Task C)

(iii) Excavating (cut) and hauling 9000 cu.m of soil to be used as fill on section of road 1000 m away (referred to as Task D hereinafter).

(iv) Spreading following (ii) and (iii) above

(v) Compacting following (iv) above

5.2.2 <u>The Three Storeyed Building</u>

5.2.2.1 <u>General</u>

A three storeyed reinforced concrete residential building with a floor area of approximately 170 square metres per storey is examined. A total of ten such buildings are to be constructed. This analysis concerns the construction of the basic structural frame only since the installation of services and other finishes offer little or no scope for substitution of various methods of execution.

Like in the road project, it is assumed that the terrain is flat or if sloping then the slopes are not greater than 5%. The soil encountered on the site is assumed to be uniform and cohesive and that where excavated material need to be hauled away, the haul distance does not exceed 2.0 Km.

5.2.2.2 <u>The Foundation</u>

The foundation consists of a reinforced concrete strip footing along all the load-bearing concrete block walls.

5.2.2.3 <u>The Superstructure</u>

The building extends 2 floors above the ground floor with the same layout for each floor. All suspended floors are 125mm thick reinforced concrete cast in-situ slabs. All loads are carried by loadbearing concrete block walls.

5.2.2.4 <u>The Works</u>

The work includes:

(a) <u>Earthworks</u>

(i) Bush clearing (medium bush) and grubbing (1780 sq.m)

(ii) Excavating over site up to 200 mm deep to remove top soil (356 cu.m) and haul to a site 200 m away (referred to as Job 1 hereinafter)

(iii) Excavate 890 cu.m of soil to required levels and haul to a site 200 m away (referred to as Job 2 in later chapters)

(iv) Excavate 1690 cu.m of soil for foundation trenches not (exceeding 1.5 m deep) and stockpile on sides for backfilling (referred to as Job 3 in later chapters)

(b) Concreteworks

(i) Blinding concrete (86.0 cu.m, 50 mm thick) over all foundation trenches (later on referred to as Job A)

(ii) Concrete foundations (340.0 cu.m) (Job B hereinafter)

(iii) Concrete ground floor slab (170.0 cu.m) (referred to as Job C in later chapters)

(iv) Concrete first and second floor slabs, stairs and beams (687.0 cu.m) (referred to as Job D in other chapters)

5.2.3 The Oxidation Ponds Project

5.2.3.1 General

This project involves the construction of a waste water treatment system. The oxidation ponds system includes 3 ponds in a series (anaerobic, facultative and maturation) intended to serve a population of up to 800 persons.

The appropriate sizes of the ponds according to Wilson (1981) for this population are summarised in Table 5.1 below.

Table 5.1 Pond Size Requirements

| Pond type | Pond Area sq.m | Max Depth m | Slopes | Dimensions m |
|---|---|---|---|---|
| Anaerobic | 6670 | 2.0 | 1:2 | 70 x 95 |
| Facultative | 4444 | 2.0 | 1:2 | 50 x 90 |
| Maturation | 4444 | 2.0 | 1:2 | 50 x 90 |

5.2.3.2 The Works

(a) Earthworks

(i) Grubbing (medium bush) and clearing site (20400 sq.m)

(ii) Excavate over site to remove top soil (4080 cu.m) and haul to 1500 m (Task 1 hereinafter)

(iii) Excavate to required depth ( 27932 cu.m) of which 20000 cu.m is to be hauled to 175 m (Task 2) and 7932 cu.m is to be hauled to a spoil heap 2000 m away (Task 3)

(b) Concreteworks

The slopes and floor of the ponds are to be lined with a 50 mm thick layer of concrete class 1:2:4. The total surface area to be concreted is about 16046.0 sq.m. Two alternative methods of concreting are considered.

(i) Alternative 1 : This alternative involves in-situ concreting.
Volume of concrete is 803.0 cu.m (referred to as Job A in later chapters)

(ii) Alternative 2 : This involves placing of precast concrete units on the required area.

## 5.3 THE INPUT RESOURCES REQUIRED FOR ALL THE PROJECTS

### 5.3.1 General

From the previous section, it can be noticed that concrete work is substantial in both the three storeyed building and the oxidation ponds projects. The resources required for earthworks and concrete works are to be examined.

Based on the fact that most construction activities can be executed in several ways, this section analyses various equipment and labour resources that are to be employed for the various activities that comprise earthworks and concreteworks for the projects described in section 5.2.

Before calculating the total input of resources for each of the projects, it is necessary to know the productivity of individual resources for the different activities.

The productivity rates used in this study have been obtained from recorded data from a variety of sources such as ILO, World Bank, IBRD and other organisations that have been concerned with labour/capital substitution in civil engineering work especially in developing countries (e.g. in Kenya, Thailand, India and The Philippines).

Whenever possible, data based on studies in Kenya has been used but where productivity rates are not available, data on similar activities from studies carried out in other countries has been adopted and adjusted to suit Kenyan conditions.

5.3.2 Earthworks

Activities comprising earthworks are bush clearing and grubbing, excavation, loading, hauling, unloading, spreading and compaction. Various equipment can be used for one or several of these activities. For each of these activities, the equipment and labour options are examined below.

5.3.2.1 Bush Clearing and Grubbing

This activity involves removal of vegetation (roots included). Two methods considered for this study are:

(i) By use of hand tools

This option involves use of appropriate tools (hoes, heavy duty rakes and shovels) to clear bush and remove roots.

Productivity (de Veen, 1980)

The output for bush clearing for dense to medium bush in firm soil and covering the whole area is 12.5 sq.m/man-hr. 30 workers are employed on the gravel road project, 20 on the three storeyed building project and 30 on the oxidation ponds project.

(ii) By use of a Bulldozer

The bulldozer considered for this option is a CatD6.

Productivity (McCleary, Allal and Nilsson, 1976)

The productivity is taken to be 357 sq.m/hr for dense to medium bush. 1 bulldozer is used on the gravel road project, 1 on the three storeyed building project and 3 on the oxidation ponds project.

5.3.2.2 Excavation and loading

There are two distinct types of excavation equipment and tools; one type carries out excavation only and another type can perform both excavation and loading (sometimes even more activities).

The material to be excavated is assumed to be a cohesive firm soil. The excavation equipment used for this work is:

(i) Bulldozer Option 1 (Performs all earthworks tasks except compaction)

(ii) Bulldozer Option 2 (Used only for excavating and loading onto hauling equipment)

(iii) Bulldozer Option 3 (For Excavating and stockpiling)

(iv) Bulldozer Option 4 (For Excavating and stockpiling on sides as is required in the building project excavation of foundation trenches)

(v) Hand Tools

(i) Bulldozer (Option 1)

This option involves performing the excavate, load, haul, unload and spread activities by one equipment and is considered suitable only where the hauling distance is less than 100 m. The dozer has a bucket capacity of 2.29 Cu.m and has a straight blade.

Productivity (Harris,1981)

The ideal output for a 2.29 Cu.m straight blade dozer is 45.0 Cu.m/Hr with the following assumptions:

(i) Dozing speed is 3 Km/Hr

(ii) Return speed is 6 Km/Hr

(iii) Manoeuvring time is 0.15 minutes

(iv) Uninterrupted production

(v) Volumes are excavated, hauled and spread as required

Allowing for losses due to weather (10%), breakdowns (5%), operator skill (7%), manoeuvring (8%) and waiting (10%), the actual output is assumed to be 60% of the ideal. A further allowance for soil type of 15% is assumed. The actual output used in this study then becomes;

Output (bulked volume) = 45.0 x 0.6 x 0.85 = 23.0 Cu.m/Hr.

Labour required - 1 operator per bulldozer

(ii) Bulldozer (Option 2)

The bulldozer in this option is used to perform the task of excavation and loading onto hauling equipment. One major assumption is that the distance travelled for loading does not exceed 25.0 m

Productivity (Harris, 1981)

The ideal output for a 2.29 Cu.m straight blade dozer for this particular option is 170.0 Cu.m/Hr with assumptions as for option 1 except that assumption (v) now becomes; Volumes are excavated and loaded onto hauling equipment.

Allowing for losses and soil type;

Output (bulked Volume) = 170.0 x 0.6 x 0.85 = 86.0 Cu.m/Hr.

Labour required - 1 operator per bulldozer

(iii) Bulldozer (Option 3)

This option involves the tasks of excavation and stockpiling only.

Productivity

The productivity is considered to be the same as for Bulldozer Option 2 under the same assumptions. Hence Output is 86.0 Cu.m/Hr.

Labour required - 1 operator per bulldozer

(iv) Bulldozer Option 4

This option is only to be considered for the three storeyed building project excavation of foundation trenches. The excavated material is stockpiled on the side of the trenches for backfilling.

Productivity

The productivity is considered to be the same as for bulldozer options 2 and 3 under the same conditions.

Hence output is 86.0 cu.m/hr with labour required being 1 operator per bulldozer.

(v) Hand Tools

The hand tools used for excavation include hoes, rakes, shovels and jembes.

Productivity (de Veen, 1980)

For excavation and loading to a height not greater than 1.0m (e.g. to wheelbarrows and trailers), the output is 0.5 Cu.m/Hr. This output is based on the following assumptions:

(i) Soil is firm and cohesive

(ii) Tools used are appropriate

(iii) Throwing distance is from 3.5m to 4.5m

(iv) Taskrate payment method is used

Labour required - 1 unskilled labour unit for every unit of hand tool employed.

5.3.2.3 Hauling

There is a wide variety of hauling modes ranging from entirely labour based methods to fully equipment based methods. The choice of method of hauling depends on many factors which include site conditions, volume of load to be moved and type of material.

The assumptions to be made in this study are:

(i) The site conditions are such that a wide range of hauling equipment can be utilised;

(ii) The haul route slopes are not greater than 5% and that bends and curves are a minimum;

(iii) Payment is on taskwork;

(iv) All the working tools and equipment are in good order.

Various modes of hauling are examined (other than where hauling is part of another task as is achieved with Bulldozer Option 1 for excavation) and their productivities based on the above assumptions among others are given.

The hauling modes considered in addition to hauling by a bulldozer option 1 are:

(i) Wheelbarrow

(ii) Tractor/Trailer combination Option 1 (Loaded mechanically by excavating equipment and unloaded manually)

(iii) Tractor/Trailer combination Option 2 (Loaded and unloaded manually)

(iv) Flat Bed Truck Option 1 (Loaded by excavating equipment and unloaded manually)

(v) Flat Bed Truck Option 2 (Loaded and unloaded manually)

(vi) Tipper Truck

(i) Wheelbarrow

A number of different designs of wheelbarrows are available. These include single wheel or two wheel barrows, solid tired or pneumatic tired. A single wheel tired wheelbarrow which weighs about 30 Kg and of capacity 0.065 Cu.m is considered for this study.

In addition to the assumptions already mentioned, it is assumed that there are more wheelbarrows than haulers so that a loaded wheelbarrow is always ready for the hauler thus minimising waiting time.

Productivity (Tech. Memo No 13, 1975)

Using productivity data from field studies in India and Indonesia, the hauler input coefficient (manhours per unit of output) was found to be;

Manhours (working Time)/Cu.m = 0.25 + (0.0076 x H) where H is the Haul length in metres.

This relationship was amended using data from Kenya (de Veen, 1980) and the output in Cu.m/hr for hauling, unloading and spreading was found to be;

Output = 1/(0.313 + 0.0095 x H) for loose soil where H is as defined above.

Hauling by wheelbarrow is limited to distances not greater than 200.0 m for this study.

Labour required - 1 unit of unskilled labour per wheelbarrow

(ii) Tractor/Trailer combination Option 1

In this option, the trailer (of capacity 3.0 Cu.m) is loaded mechanically and unloaded manually (suitable where excavation is done by heavy equipment).

Productivity

Assuming that the excavating equipment is fitted with a loader such that the loading output is 86.0 Cu.m/Hr (bulldozer Option 2 ) and that the tractor/trailer travels at a speed of 20Kph when loaded and unloaded and that unloading is done by a gang of 8 workmen, a hauling output of 86.0 Cu.m/Hr is achieved with a team of 11 trailers for haul distances of upto 2000 m. (see Appendix A)

Spreading is considered to be part of this hauling method.

Labour required - 1 operator per truck
- 8 unskilled labour units per tractor load

(iii) <u>Tractor/Trailer combination Option 2</u>

This option involves manual loading and unloading. The method of working is based on obtaining the maximum possible utilisation from the mobile unit (the tractor) and only the trailers are idle while being loaded. This requires that a trailer is always available when the tractor completes one cycle.

The method of operation consists of a loaded trailer being hitched to a tractor which is hauled to a suitable position where it is unloaded manually. The tractor then pulls the empty trailer to the borrow area where another loaded trailer is ready for hauling. The empty trailer is unhitched at the borrow area and the loaded trailer is hitched to the tractor and the same sequence of operation is repeated.

<u>Productivity (de Veen,1980)</u>

The productivity of tractor/trailer combination that is loaded and unloaded manually is based on the following assumptions and conditions:

(a) One tractor and two trailers, with ample room for manoeuvring and loading
(b) Manoeuvring time is 8 to 20 minutes per cycle
(c) Excavation and stockpile manually at 2 to 3.5 loose Cu.m per man-day
(d) Loading at 7 to 10 loose Cu.m per Man-day
(e) Spreading at 12 to 15 loose Cu.m per Man-day
(f) Volume per load is 3 loose Cu.m
(g) Working time per day is 8 Hours
(h) Rest and other allowances (e.g taskwork bonus) is 40%
(i) Tractor available time is 6 Hours per day
(j) Good supervision and organisation
(k) Good quality tools
(l) Good motivation for tractor operators and labourers

With these conditions and assumptions and with a well maintained haul route, the output was found to be;

Output (Cu.m/Hr) = 3.2 - 0.0005 x H where

H = Haul distance in Metres .

Labour required - 1 operator per tractor
- 8 unskilled labour units to load
- 8 unskilled labour units to unload

(iv) Flat Bed Lorry Option 1

In this option the flat bed truck (of capacity 4.0 Cu.m) is loaded mechanically and unloaded manually (like the tractor/trailer option 1).

Productivity

Assumptions being the same as for the tractor/trailer option 1, a team of 10 trucks gives a productivity of 86.0 Cu.m/Hr.

Labour required - 1 driver per truck
- 8 unskilled labour units to unload and spread each truck load

(v) Flat Bed Lorry Option 2

The truck is loaded and unloaded manually.

Productivity (Tech. Memo No 3, 1975)

Based on data taken from field studies in India and Indonesia, productivity rates for haulage with a flat bed truck is derived from the following equation;

$\ln V = 7.541 + 0.894 \ln LT - 0.645 \ln H$

where V = Volume of homogeneous loose material in Cu.m

LT = Truck time in Hours

H = Haul distance in metres

The following assumptions were made:

(a) Excavation productivity is 0.5 Cu.m/Man hour (for manual excavation in Kenya in firm soil with throwing distance of 0 - 4 m, and with taskrate payment method, productivity is 0.44 - 0.56 Cu.m/Hr hence compares well with productivities in India and Indonesia)

(b) Loading productivity is 0.5 Cu.m/Man hour (loading productivity in Kenya is 0.88 - 1.25 Cu.m/Man hour for a loading height of 1 - 2 m hence compares acceptably with this assumption) and that unloading productivity is 6.0 Cu.m/Man hour

(c) Average truck speed is 20.0 Kph

(d) Truck capacity is 4.0 Cu.m

(e) A gang of 8 workmen per truck is used for loading and unloading

With these assumptions, the productivity was found to be;

$$\text{Output(Cu.m/Hr)} = e^{7.541 - 0.645 \ln H}$$

where; H is the haul distance in metres.

Labour required - 1 driver
- 8 unskilled labour units to load each truck
- 8 unskilled labour units to unload and spread each truck load

(vi) <u>Tipper Truck</u>

A tipper truck with capacity of 4.0 Cu.m is considered. Loading is achieved by the excavating equipment (bulldozer option 2) being fitted with a loading bucket. The tipper is self unloading.

Productivity

Assuming a travel speed of approximately 20 Kph and that the excavator's productivity for excavating and loading is 86.0 Cu.m/Hr, then a team of 4 trucks gives a hauling productivity of 86.0 Cu.m/hr for haul distances of up to 2000 m. (see Appendix A)

Labour required - 1 operator per truck

5.3.2.4 Spreading

Most of the earthworks operations in civil engineering construction require that materials be spread evenly in layers to facilitate further operations such as compaction.

The material to be spread may be either;

(i) produced locally adjacent to its final position in the works, or

ii) brought from elsewhere and unloaded more or less in it's final position, or

iii) brought from elsewhere and stacked in conveniently placed stockpiles.

For both locally produced and stockpiled material, spreading involves a loading/hauling (over a short distance)/unloading sequence. The spreading may follow the unloading as a separate activity, or it may be combined with the unloading activity, the choice depending primarily on the type of container or equipment used for hauling. Thus, for example, the heaps resulting from a tipper truck haulage require to be spread whereas the wheelbarrow can be unloaded at the materials' final position with minimum need for further spreading.

The range of tools and equipment used for spreading considered for this study other than where spreading is part of another major task (as is achieved by Bulldozer Option 1, Tractor/Trailer options 1 and 2, both options of flat bed truck and wheelbarrow hauling) are:

(a) Grader

(b) Hand Tools

(a) Grader

The grader considered is a 125 Hp with a blade length of 3.5 - 4.0 metres.

Productivity

The productivity is taken as 115.0 Cu.m/Hr (McCleary, Allal and Nilsson, 1976).

Labour required - 1 operator per grader

(b) Hand Tools

The range of hand tools used for spreading include spades, shovels hoes and rakes.

Productivity

The productivity of hand tools in spreading depends amongst other factors, on the haulage mode. Unfortunately there is insufficient data to separate out this effect, although it can be assumed that all other factors (e.g. soil type, job conditions etc) being constant, the productivity is higher for headbasket or wheelbarrow haulage than it is for haulage modes in which the soil is deposited in a single relatively large heap (e.g. from a tipper truck).

With suitable tools and high incentives, the productivity of hand tools for spreading used in this study is taken as 1.5 Cu.m/Hr (de Veen, 1980).

5.3.2.5 Compaction

Fill for the construction of roads, backfilling of trenches and foundations is normally loose and bulked after excavation, hauling and spreading and must be compacted to prevent distortion and settlement when in place.

The attainable compaction, measured by the change in density, depends very much upon the type of material and the moisture content. In order to obtain satisfactory compaction where required, several types of equipment have been considered.

These are:

(a) An 8 Ton smooth wheel self propelled roller

(b) A 3.8 Ton tractor towed smooth wheeled roller

(c) A 2 Ton vibrating plate compactor

(d) A 200 Kg Hand Propelled Vibrating roller

Table 5.2 Compactinq Equipment Productivities (Beenhakker, 1987)

| EQUIPMENT TYPE (as categorised above) | a | b | c | d |
|---|---|---|---|---|
| Width compacted (m) | 1.78 | 1.83 | 0.86 | 0.61 |
| Speed of rolling (m/min) | 50.0 | 40.0 | 10.0 | 10.0 |
| Number of passes required | 4 | 6 | 2 | 8 |
| Area compacted per hour (sq.m) | 1320 | 730 | 258 | 46 |
| Depth of compacted layer (mm) | 150 | 250 | 300 | 80 |
| Output of compacted soil (Cu.m/Hr) | 198 | 180 | 77 | 3.7 |
| Output (allowing for an overall efficiency factor of 60%) in Cu.m/Hr | 118.8 | 108.0 | 46.2 | 2.2 |

Labour required - 1 operator for each equipment

### 5.3.3 Concrete Works

Concrete works is categorised in this study to be comprised of the tasks of mixing, hauling and placing. Each of these tasks is examined and the viable options of equipment and labour are analysed.

(a) Mixing

To produce high quality concrete, it is essential that the concrete be thoroughly mixed so that all the components are evenly distributed.

Concrete mixing can either be done by hand or by machine. Hand mixing is only appropriate where small quantities of concrete of low strength are required. The projects investigated in this study that require concrete are the three storeyed building and the oxidation ponds. These require large amounts of concrete and hence hand mixing is considered inappropriate.

Two different capacities of the tilting drum type of concrete mixer are to be used. The types are 10/7 and 14/10.

Output (Enterkin and Reynold, 1978)

A continuous production geared to the output of the placing squad is aimed at. The table below gives the productivities applied in this work.

Table 5.3 MIXER OUTPUT

| Size | | Output Cu. m/Hr | Number of men attending | |
|---|---|---|---|---|
| Imperial Cu. ft | Metric Cu. m | | Skilled | Unskilled |
| 10/7 | 0.280/0.200 | 2.00 | 1 | 2 |
| 14/10 | 0.400/0.280 | 2.80 | 1 | 3 |

(b) Hauling

To maintain high quality concrete that has uniform properties, it is essential that all handling and transporting after mixing be done carefully to avoid segregation and early hardening.

Various methods of hauling concrete to placing point exist and the choice of method usually depends on two basic considerations;(1) the location and volume of concrete pour and (2) the methods chosen for mixing the concrete and pouring it into the concrete forms.

The methods of hauling considered for this study are:

(i) Wheelbarrow
(ii) Pumping
(iii) Hoist
(iv) Crane and skip

(i) Wheelbarrow

The wheelbarrow considered for transporting concrete is the same as the one specified for earthworks.

Productivity

For hauling distance not exceeding 25.0 m, it takes 0.75 Hr to 1.0 Hr per worker per cubic metre of concrete (Enterkin & Reynolds, 1978).

Hence, Output is 1.33 to 1.0 Cu.m/Hr.
Amending for overall efficiency (taken as 60%), then
Output is 0.8 to 0.6 Cu.m/Hr.
Output used for this study is 0.7 Cu.m/Hr.
Labour required - 1 unskilled labour unit per wheelbarrow

(ii) Pumping

In this method of hauling, concrete is hauled through a series of flexible pipes of 100 mm diameter that are coupled together. The concrete pump can move concrete for a horizontal distance of upto 300 m and upto a vertical distance of upto 100 m. The maximum distance for a particular pump however, depends on the mix design.

Productivity (Harris, 1981)

For this study, a concrete pump with a line pressure of 18 N/sq.mm with a pipe diameter of 100mm is used. The ideal output of such a pump and for concrete with a slump of 50 to 75 mm is 35 to 45 Cu.m/Hr for horizontal distance of up to 300 m and vertical distance of up to 100 m. Allowing for only 60% overall efficiency, output is 21 to 27 Cu.m/Hr

The output assumed in this study is 22 Cu.m/Hr.

Labour required - 1 pump operator
- 2 unskilled labour units at loading point
- 3 skilled labour units (masons) to finally place the concrete in the forms using hand tools.

(iii) Hoist

A free standing hoist capable of lifting upto 1000 Kg to landing heights of upto 25 m is considered. A set of wheelbarrows is used to transport concrete from the mixer to the base of the hoist (for a distance not exceeding 25 m).

Productivity (Harris, 1981)

For a hoist speed of 40 m/min and a discharge height of upto 25 m, the ideal output for a 0.76 Cu.m skip is about 19 Cu.m/Hr. Allowing for losses and breakdowns, an efficiency of 60% is assumed hence productivity is 11.4 Cu.m/Hr.

Labour required - 1 operator
- 4 unskilled labour units with wheelbarrows to fill the hoist bucket at the mixing level
- 4 unskilled labour units with wheelbarrows to haul concrete from hoist platform at floor level to placing point
- 3 skilled labour units (masons) with hand tools to finally place concrete

(iv) Crane and Skip

The crane to be used is an 8 Ton mobile crane.

Productivity (Harris, 1981)

With a skip of 0.38 Cu.m (0.5 Cu.yards) and for a height of up to 25 m, the ideal output is 7.0 Cu.m/Hr. Allowing for an efficiency of 60%, productivity is 4.2 Cu.m/Hr. This is the output used in this study.

Labour required - 1 operator
- 2 unskilled labour units to load skip at mixing level
- 2 unskilled labour units to unload skip at placing point
- 2 skilled labour units (masons) to finally place concrete in the forms

## 5.4 SUMMARY

A summary of the projects to be investigated (a gravel road, a three storeyed building project and an oxidation pond system) have been given and the major works for each of them outlined.

Earthworks (which comprises excavating (E), loading (L), hauling (H), unloading (U), spreading (S) and compacting) and concreteworks (which is considered to include mixing, hauling and placing) were found to be the major works with a wide range of methods of execution.

For each of the activities, various options of equipment and labour that can be used and their productivities have been outlined and are summarised in Table 5.4 given below.

Table 5.4 A Summary of Work Particulars and Options Available

| WORK PARTICULARS | OPTIONS CONSIDERED |
|---|---|
| **Earthworks** | |
| Bush Clearing & Grubbing | 1. Bulldozer<br>2. Hand Tools |
| Excavation & Loading | 1. Bulldozer Option 1 (E,L,H,U,S)<br>2. Bulldozer Option 2 (E,L)<br>3. Bulldozer Option 3 (E)<br>4. Bulldozer Option 4 (E)<br>5. Hand Tools (E,L) |
| Hauling & Unloading | 1. Wheelbarrow (H,U,S)<br>2. Tractor/Trailer Option 1 (H,U,S)<br>3. Tractor/Trailer Option 2 (H,U,S)<br>4. Flat Bed Lorry Option 1 (H,U,S)<br>5. Flat Bed Lorry Option 2 (H,U,S)<br>6. Tipper Truck (H,U) |
| Spreading | 1. Grader<br>2. Hand Tools |
| Compacting | 1. An 8 Ton Smooth Wheeled Self Propelled Roller<br>2. A 3.8 Ton Tractor Towed Smooth wheeled Roller<br>3. A 2 Ton Vibrating Plate Compactor<br>4. A 200 Kg Hand Propelled Vibrating Roller |
| **Concreteworks** | |
| Mixing | 1. A Tilting Drum Mixer size 10/7<br>2. A Tilting Drum Mixer size 14/10 |
| Hauling & Placing | 1. Wheelbarrow<br>2. Pumping<br>3. Hoist<br>4. Crane and Skip |

# CHAPTER 6

# METHOD OF ANALYSING DATA

## 6.1 GENERAL

To be able to select the most suitable combination of resources (equipment and labour) for carrying out various construction activities, it is necessary that a method be developed to calculate the times and costs that result from various compatible combinations of options.

This chapter is aimed at relating the method used in this study. A databased computer programme has been developed and used to calculate the costs and durations for various methods of construction.

The unit rates used are as explained in Chapter 4 and the productivity rates used are as related in Chapter 5.

To demonstrate the working of the method, the Gravel Road Project data has been used.

## 6.2 REVIEW OF DATABASE MANAGEMENT SYSTEMS

A database management system, such as dBXL which is used in this study, is a means of organising and using information stored in databases. A database is a computer file, created by a database package, that stores data in an orderly fashion. Within a database, data is organised in individual RECORDS, each containing information related to a single entity. Within records, the categories of information are the FIELDS of the database.

While databases and database management systems are similar to older methods of organising information, their efficiency and potential usefullness are much greater. With the systems programming language, one is able to create customised application for specific needs.

The ease with which data can be edited, retrieved and searched (e.g.

searching for records within a database that match some particular description) makes database management systems most appropriate for purposes of this study.

## 6.3 GENERAL OUTLINE OF THE SYSTEM USED

| INPUT | | PROCESSING | | OUTPUT |
|---|---|---|---|---|
| Databases<br><br>1. Activities for given job<br>2. Resources required for the different tasks | → | Program to manipulate data as required for compatible resources | → | Summary Database which includes;<br><br>1. Resource details<br>2. Task durations and costs for various methods |

The output from this system enables one to select the most suitable (most appropriate) method of construction.

## 6.4 OUTLINE OF INPUT DATA

<u>Step 1</u>: Identify the major tasks for the particular project. The tasks of particular interest here are those that can be executed in more than one way. The quantities of work are also calculated. Enter the task details into appropriate database.

<u>Step 2</u>: Establish a sequence of operation using a network diagram to help determine interdependence of activities.

<u>Step 3</u>: Establish the types of equipment and labour resources to be employed for particular activities from the options available (as given in Chapter 5) and the units of each that are available. Enter the resource details into databases.

For interdependent activities, compatibility (or balancing) of equipment and labour resources is checked and maintained (e.g in an earthworks task, a wheelbarrow cannot be used for hauling when excavation and loading is done by a bulldozer).

The above steps are demonstrated below using the Gravel Road Project.

Step 1: The major activities to be carried out are;

Task C - Cut to fill 2500 Cu.m of soil, lead 200 m.
Task D - Cut to fill 9000 Cu.m of soil, lead 1000 m.

These details are entered in WORKS database file (the database is shown in Appendix C).

The task of cut to fill is considered to be composed of the tasks of Excavation (and loading), Hauling (and unloading), Spreading and Compaction.

The sequence of operation is;

Excavation ⟶ Hauling ⟶ Spreading ⟶ Compaction

Four databases have been created for each of these elements of work. The databases are; EXCEQPT, HAULEQPT, SPREADEQ and COMPEQPT respectively. A brief description of the particulars of each of them is given below while the actual databases are given in Appendix C.

EXCEQPT

The fields include:

Short : An abbreviation of the type of excavation equipment
Descript : A brief description of the equipment type (as given in Chapter 5)
Output : Includes the productivity of equipment (in units of work done per resource hour)
U_Rate : Shows the unit rate for using the equipment
U_Avlb : Includes the number of units of the particular resource available
Comp_With : Includes the abbreviation of the equipment(s) for the next activity (in this case Hauling) which is compatible with the excavation equipment under consideration.

HAULEQPT

The fields include:

Short : As above but for hauling equipment
Descript : As above

Capacity : Includes the volume of earth carried by one unit of hauling equipment (where given as equal to zero, then hauling is part of the preceding activity, in this case excavation)

Max_haul : Includes the maximum haul distance beyond which the equipment type cannot be used.

Output : As above

U_Rate : As above

U_Avlb : As above

Comp_With : As above but the next activity is spreading

SPREADEQ

The fields include:

Short, Descript, Output, U_Rate, U_Avlb and Comp_with all of which are as explained above except for Comp_with where the next activity is compacting.

COMPEQPT

The fields include Short, Descript, Output, U_Rate and U_Avlb all of which are as explained above.

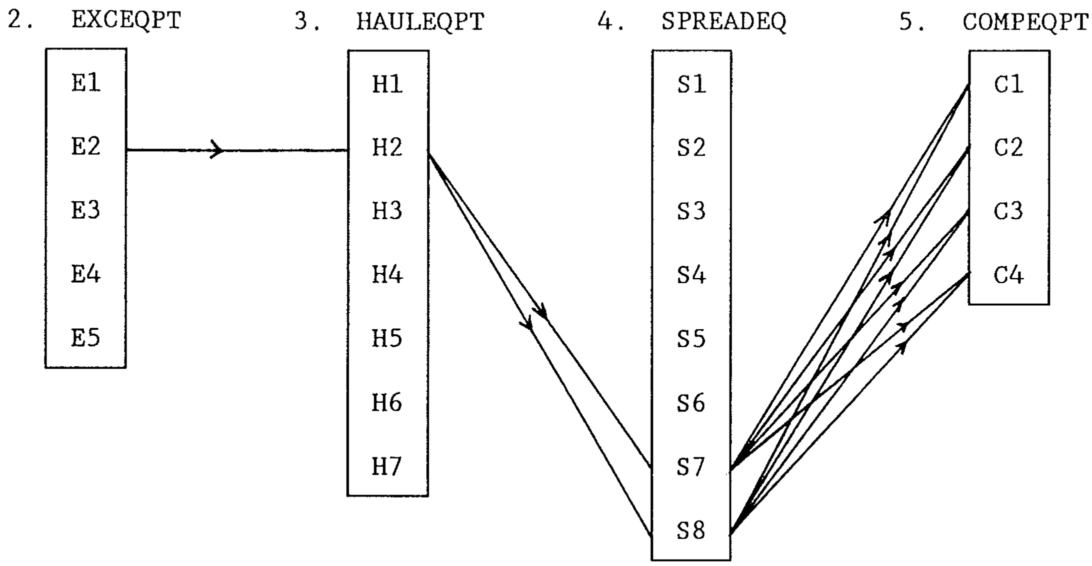
Where U_Rate, Output, and/or U_Avlb is given as zero, then the equipment under consideration is the same one that was used to carry out the preceding activity.

All the databases are shown in Appendix C.

## 6.5 OUTLINE OF METHOD

The method involves selection of a particular job and investigating the possible alternative viable methods of construction and calculating the durations and costs of each method.

Shown below are some of the alternative methods possible for carrying out Task C (see WORKS dbf) for the gravel road project. The terms and abbreviations used are as explained in earlier sections of this chapter.




The arrows shown above represent just a few possible equipment combination options for carrying out the task selected in the WORKS dbf.

## 6.6 DURATIONS AND COSTS FOR THE VARIOUS OPTIONS

### 6.6.1 Duration

The duration of a particular task is arrived at from the individual durations required to carry out individual activities that constitute the task under consideration. For example, the time taken to carry out the task of excavating 2500 cu.m of soil and hauling for 200m (Task C) in the Road Project is the maximum of time to excavate, time to haul, time to spread and time to compact since these activities are interdependent. The final task duration will therefore depend on the slowest operation in this case.

Each of these times is calculated as shown below;

$$\text{Activity time (acttime)} = \frac{\text{Quantity of work (as shown in WORKS dbf)}}{\left(\text{Output (of particular equipment)}\right) \times \text{Units Available (U\_Avlb)}}$$

Where U_Rate, U_Avlb or output for any particular equipment is given as zero in the appropriate database, then the activity under consideration is executed by the same equipment that carried out the previous activity thus acttime is taken as zero in such a case. An example of such a case is Method 1 explained below for carrying out Task C.

The method explained above for calculating task duration is demonstrated below for Task C which is quantified as 2500 Cu.m (see WORKS dbf). Two methods are shown below;

Method 1: Where all activities except compaction are done by one item of equipment, bulldozer option 1 (i.e C1, H1, S1) and compaction is achieved by using the 8 Ton smooth wheeled self propelled roller (C1).

Method 1 Duration

Excavation time (exctime) = 2500/(23.0 x 1) = 108.70 Hrs

Hauling time (haultime) = 0 Hrs

Spreading time (spreadtime) = 0 Hrs

Compacting time (comptime) = 2500/(118.0 x 1) = 21.19 Hrs

Hence acttime = Maximum of 108.7, 0, 0, 21.19 = 108.70 Hrs

Method 2: Where different kinds of equipment are used for the various activities e.g. excavating with bulldozer option 2 (E2), hauling with tipper truck unit (H2), spreading with the grader (S7) and compacting with the 8 Ton smooth wheeled self propelled roller (C1).

Method 2 Duration

Exctime = 2500/(86.0 x 1) = 29.07 Hrs

Haultime = 2500/(86.0 x 1) = 29.07 Hrs

Spreadtime = 2500/(115.0 x 1) = 21.74 Hrs

Comptime = 2500/(118.0 x 1) = 21.19 Hrs

Hence acttime = Maximum of 29.07, 29.07, 21.74, 21.19 = 29.07 Hrs

### 6.6.2 Cost

The total cost of carrying out a task is considered to be the sum of the costs of carrying out the individual activities that comprise that task. For example, the cost of carrying out Task C in the Road Project is given as the sum of cost of excavating, cost of hauling, cost of spreading and the cost of compacting.

The cost of each activity is based on the unit rates as they are given in the individual databases for the various activities. Because of the interdependence of these activities, the cost of each is considered to depend on the total task time (acttime) as calculated above in Section 6.6.1.

The general formula is;

Activity cost (actcost) = Unit rate x Acttime x Units Available

The same examples used to demonstrate the calculation of duration are used here for the cost calculation and the same order is followed.

<u>Method 1</u>

Excavating cost (exccost) = 877.77 x 108.70 x 1 = KSh 95413.60

Hauling cost (haulcost) = KSh 0.00

Spreading cost (spreadcost) = KSh 0.00

Compacting cost (compcost) = 391.74 x 108.70 x 1 = KSh 42582.14

Hence;

Actcost = KSh 95413.60 + 0.00 + 0.00 + 42582.14 = KSh 137995.74

<u>Method 2</u>

Exccost = 877.77 x 29.07 x 1 = KSh 25516.77

Haulcost = 1902.05 x 29.07 x 1 = KSh 55292.59

Spreadcost = 744.22 x 29.07 x 1 = KSh 21634.48

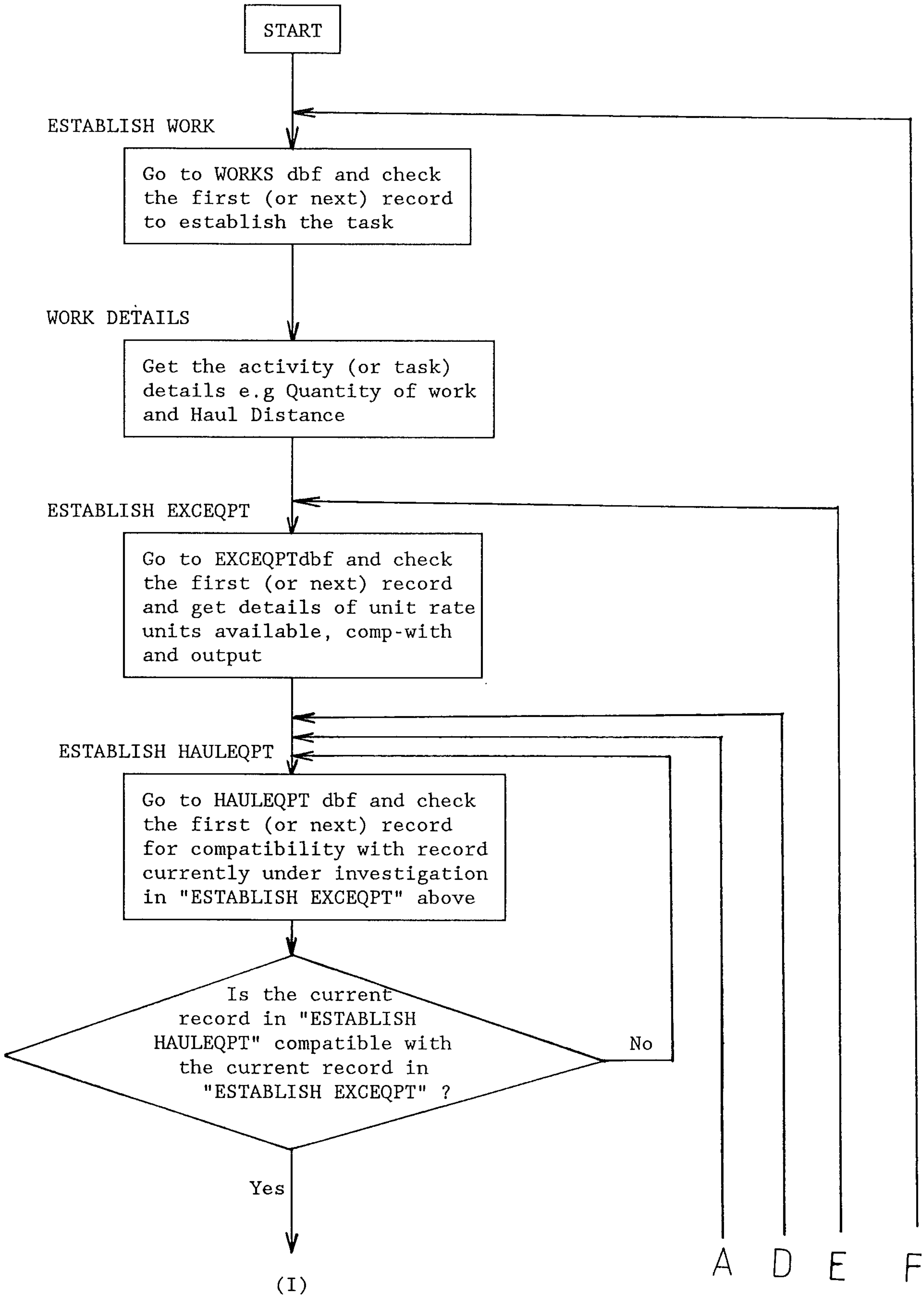
Compcost = 391.74 x 29.07 x 1 = KSh 11387.88

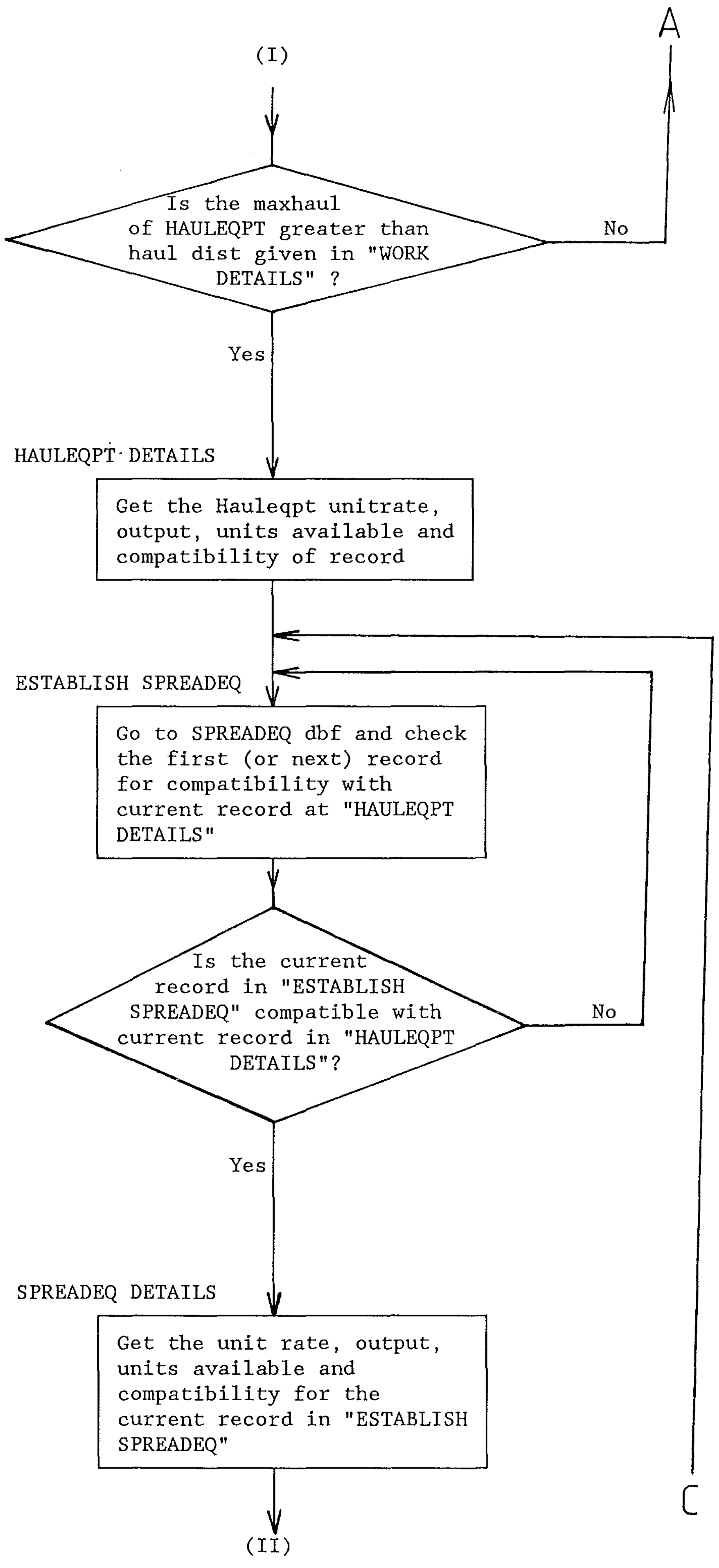
Hence actcost = Sum of the above costs = KSh 113831.72

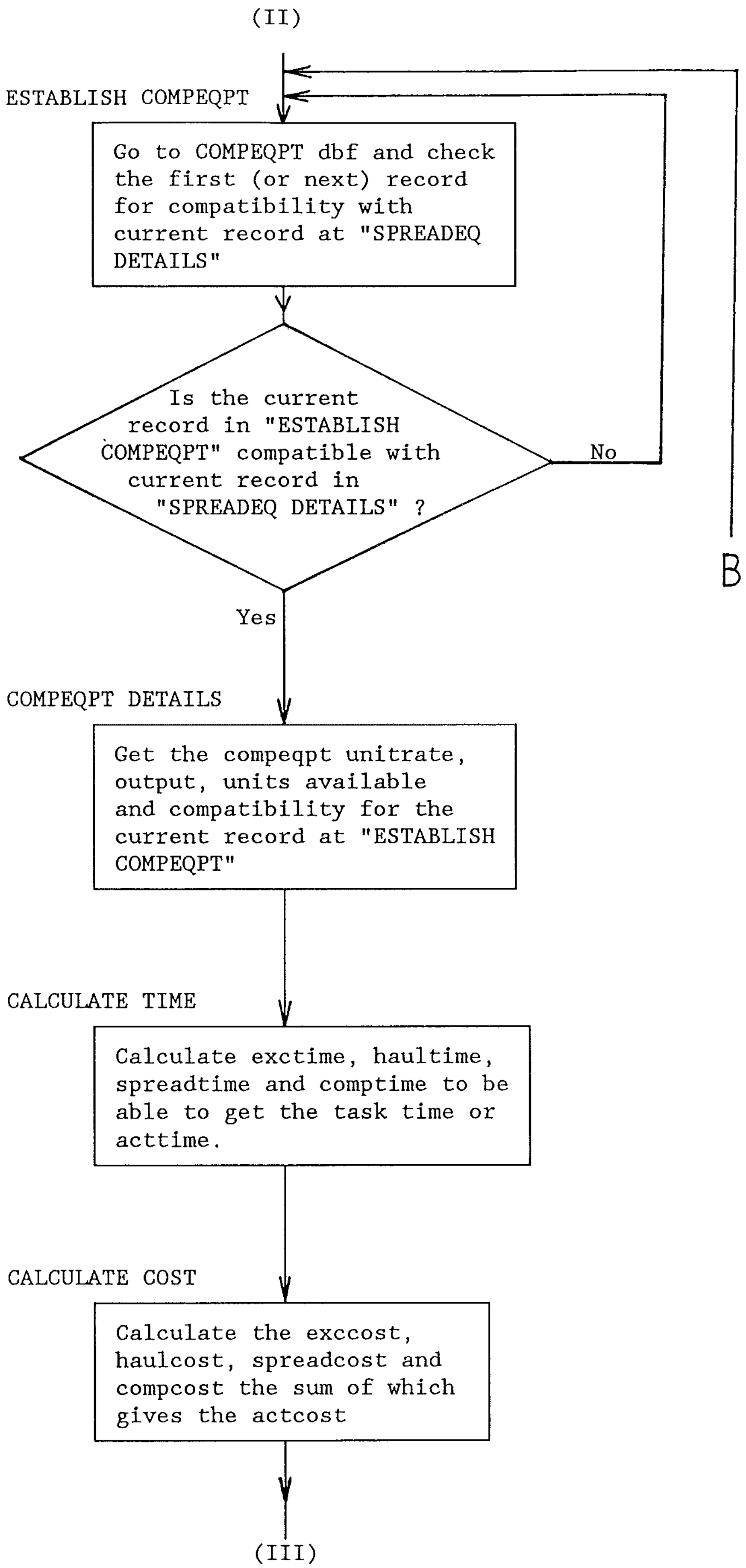
## 6.7 OUTLINE OF THE FLOW OF THE PROGRAMME

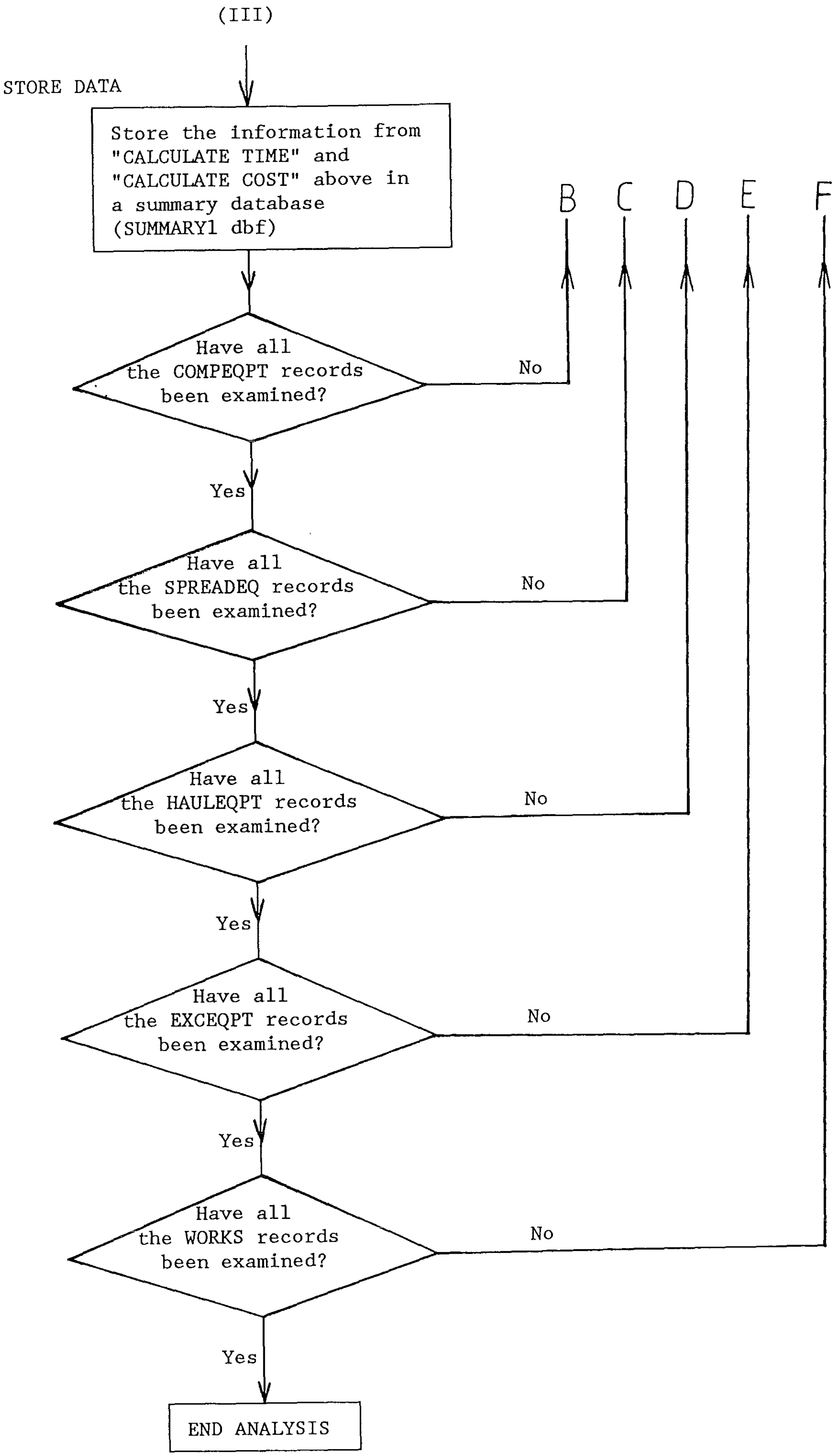
The flow diagram given below shows an outline of how the programme works. The terms used are as explained in earlier sections of this chapter.

FIGURE 6.2 FLOW CHART FOR THE GRAVEL ROAD PROJECT ANALYSIS PROGRAM




A
(I)
Is the maxhaul of HAULEQPT greater than haul dist given in "WORK DETAILS" ?
No
Yes
HAULEQPT DETAILS
Get the Hauleqpt unitrate, output, units available and compatibility of record
ESTABLISH SPREADEQ
Go to SPREADEQ dbf and check the first (or next) record for compatibility with current record at "HAULEQPT DETAILS"
Is the current record in "ESTABLISH SPREADEQ" compatible with current record in "HAULEQPT DETAILS"?
No
Yes
SPREADEQ DETAILS
Get the unit rate, output, units available and compatibility for the current record in "ESTABLISH SPREADEQ"
(II)
C


(II)
ESTABLISH COMPEQPT
Go to COMPEQPT dbf and check the first (or next) record for compatibility with current record at "SPREADEQ DETAILS"
Is the current record in "ESTABLISH COMPEQPT" compatible with current record in "SPREADEQ DETAILS" ?
No
B
Yes
COMPEQPT DETAILS
Get the compeqpt unitrate, output, units available and compatibility for the current record at "ESTABLISH COMPEQPT"
CALCULATE TIME
Calculate exctime, haultime, spreadtime and comptime to be able to get the task time or acttime.
CALCULATE COST
Calculate the exccost, haulcost, spreadcost and compcost the sum of which gives the actcost
(III)


(III)
STORE DATA
Store the information from "CALCULATE TIME" and "CALCULATE COST" above in a summary database (SUMMARY1 dbf)
B
C
D
E
F
Have all the COMPEQPT records been examined?
No
Yes
Have all the SPREADEQ records been examined?
No
Yes
Have all the HAULEQPT records been examined?
No
Yes
Have all the EXCEQPT records been examined?
No
Yes
Have all the WORKS records been examined?
No
Yes
END ANALYSIS

## 6.8 FORM OF RESULTS (OUTPUT)

Durations and costs for the various possible equipment combinations are entered into a summary database automatically as they are calculated. For the Gravel Road Project, the results are entered into the database SUMMARY1 dbf. The contents of the fields of this database are as explained below (all durations in hours and costs in KSh).

| | | |
|---|---|---|
| JOBPART | : | Includes the description of the task under consideration as it is shown in WORKS dbf |
| EEQ | : | Includes the short form or abbreviation of the excavating equipment |
| ETIME | : | The actual time the excavating equipment takes to carry out the job |
| HEQ | : | Includes the abbreviation of the hauling equipment |
| HTIME | : | The actual time required for hauling |
| SEQ | : | Includes the abbreviation of the spreading equipment |
| STIME | : | The actual time required to spread |
| CEQ | : | Includes the abbreviation of the compacting equipment |
| CTIME | : | The actual time required to compact |
| JOBTIME | : | Minimum time required to complete the task under consideration |
| JOBCOST | : | Minimum cost of the task under consideration for a particular equipment combination |
| CLASS | : | Shows the category of the method as either Labour Intensive (LI), Intermediate L (IL), Intermediate C (IC) or Capital Intensive (CI). (This is explained further in Chapter 7). This field is filled after all the other fields have been filled. |

From the summary database (SUMMARY1 dbf), one can get the cost, durations and the combination of equipment that satisfy a given condition. The full results are given in Appendix C and discussed in the next chapter.

## 6.9 OTHER CONDITIONS e.g. Different projects, unit rates and productivities

### 6.9.1 <u>Other Projects</u>

For the three storeyed building project and the oxidation ponds project, the method outlined in this chapter is followed for the earthworks except that in this case, earthworks includes only excavation and hauling. For concreteworks, the appropriate databases are created and programs which follow the same principles as the one outlined above for earthworks have been written and used for analysis.

### 6.9.2 Other Rates

The unit rates used in the example given are the market rates. To analyse the works at shadow rates, the appropriate shadow factors (as explained in Chapter 4) are used to adjust the unit rates. These are entered in the appropriate databases and the same program used to analyse the projects at shadow rates.

### 6.9.3 Different Productivities

For cases where the productivities for a particular input factor are different (as occurs in similar projects but cited in different localities) the productivity is adjusted and entered in the appropriate databases and the new durations and costs calculated.

Another major factor that affects productivity apart from different localities is the number of units of a particular resource that are available for a given job at a given time. Details of availability are established and the affected databases adjusted appropriately and new durations and costs calculated and the best method selected.

## 6.10 SUMMARY

A method that analyses possible combinations of equipment for carrying out construction activities has been presented. The method used is a computerised databased program which enables investigation of the durations and costs associated with various methods of construction. An example has been worked out to show the working of the method by using data for the gravel road project.

Detailed results are given in Appendix C while analysis of the results for the various projects at market and shadow rates is the subject of the next chapter.

# CHAPTER 7

# PRESENTATION AND DISCUSSION OF RESULTS

## 7.1 GENERAL

Results from the analysis carried out as outlined in Chapter 6 are presented and discussed. To achieve this, the various viable combinations of equipment and labour for all the projects have been categorised. Durations and costs at both market and shadow prices are presented as well.

A method of carrying out sensitivity analysis has also been presented.

## 7.2 CATEGORISATION OF METHODS

The methods available for earthworks and concreteworks vary widely from project to project (see Appendix C). Due to the complexity of categorising methods of construction, differences in opinion may arise as to whether a particular method is better classified as one category and not the other. This is therefore solely at the discretion of those analysing a particular project. The classifications presented here are, however, considered most appropriate for this study.

In all the projects, the methods of construction are considered to range from labour intensive to capital intensive for both earthworks and concreteworks. The different categories of methods are given below for each project.

### 7.2.1 The Gravel Road Project

a) Grubbing and Top Soil stripping

Methods considered are either Labour Intensive (using Hand Tools) or Capital Intensive (using a bulldozer).

b) Earthworks

The methods available for earthworks are categorised as either one of the following: Labour Intensive; Intermediate L; Intermediate C; or Capital Intensive.

(i) Labour Intensive

Where more than three quarters of the activities are carried out by manual labour, then the method is categorised as Labour Intensive. This is considered to include all the following conditions:

- excavation by hand tools
- hauling by wheelbarrow
- spreading by hand tools (or hauling device)
- compaction by any type of compacting equipment (except the 8Ton Smooth Wheeled Self Propelled Roller)

(ii) Intermediate L

Those methods categorised as Intermediate L are those in which about half of all the activities are carried out by manual labour and the rest by mechanical means. They include all the following conditions:

- excavation by hand tools
- hauling by Tractor/Trailer Option 2 or Flat Bed Lorry Option 2
- spreading by hand tools or hauling device
- compaction by any type of equipment

(iii) Intermediate C

Methods categorised as Intermediate C are those in which about three quarters of the activities are carried out by mechanical means and the rest by manual labour. They are considered to include all the following conditions:

- excavation by mechanical excavators
- hauling by Tractor/Trailer Option 2 or Flat bed Lorry Option 2
- spreading by hauling device or hand tools
- compaction by all types of compaction equipment

(iv) Capital Intensive

Capital intensive methods are considered to be those in which all the activities are carried out by mechanical means. They include all the following conditions:

- excavation by mechanical means
- hauling by tipper truck, tractor/trailer option 1 or flat bed lorry option 1

- spreading by grader or hauling device
- compaction by any equipment (except the 200Kg hand propelled Roller)

7.2.2 The Three Storeyed Building Project

(a) Grubbing and Top Soil Removal

Methods available for grubbing and top soil removal are Labour Intensive (with hand tools) or Capital Intensive (with bulldozer).

(b) Earthworks

Categorisation for earthworks is on the same lines as for earthworks in the gravel road project where the methods are categorised as either Labour Intensive, Intermediate L, Intermediate C or Capital Intensive.

(i) Labour Intensive;
- excavation by hand tools and
- hauling by wheelbarrows

(ii) Intermediate L;
- excavation by hand tools and
- hauling by tractor/trailer option 2 or flat bed lorry option 2

(iii) Intermediate C;
- excavation by mechanical means
- hauling by tractor/trailer option 2 or flat bed lorry option 2

(iv) Capital Intensive;
- excavation by mechanical means
- hauling by tipper truck, tractor/trailer option 1 or flat bed lorry option 1

(c) Concreteworks

Like in earthworks, concreteworks methods for the building project are categorised as Labour Intensive, Intermediate L, Intermediate C or Capital Intensive.

(i) Labour Intensive
- mixing by either of the mixers
- hauling and placing by using wheelbarrows

(ii) Intermediate L
- mixing by either of the mixers
- hauling and placing by use of a hoist

(iii) Intermediate C

- mixing by either of the mixers
- hauling and placing by use of a concrete pump

(iv) Capital Intensive

- mixing by either of the mixers
- hauling and placing by use of a crane and skip

7.2.3 <u>The Oxidation Ponds Project</u>

(a) <u>Grubbing, top soil stripping and other earthworks</u>

The categorisation of methods used are as explained in the Three Storeyed Building Project.

(b) <u>Concreteworks</u>

Due to the nature of the job, there are only two methods considered viable. These are Labour Intensive or Capital Intensive.

(i) Labour Intensive

- mixing by either type of mixer
- hauling and placing by wheelbarrows

(ii) Capital Intensive

- mixing by either type of mixer
- hauling and placing by use of a concrete pump

## 7.3 PRESENTATION OF RESULTS

7.3.1 <u>General</u>

Results obtained from the analysis outlined in Chapter 6 are presented in Tables CIIIa to CIIIe in Appendix C. From these results, two sets of durations and costs have been extracted based on the categories given in section 7.2. The two sets of data obtained are based on least duration and least cost. This is aimed at showing how wide the range of options of methods of construction are. This was also prompted by the fact that for some tasks, the method of construction that takes the shortest duration does not necessarily cost the least (or most). There does not seem to be any difference between the least cost options and the least duration options in the Gravel Road Project earthworks and in all the concreteworks especially when considered at market rates. There are, however, some variations when using shadow rates for equipment and labour rates as will be shown later.

All the data on costs and duration shown in Tables 7.1 to 7.5 below is obtained from the respective summary databases and is a result of analysis at market rates (summary database details are as explained in Chapter 6 section 6.8 and are presented in full in Appendix C as Tables CIIIa to CIIIe). Summary databases resulting from analysis at various shadow rates and corresponding tables of the form of Tables 7.1 to 7.5 are not presented here since they all would be in the same format as those from market rate analysis. However, though not shown in full here, various cases of shadow rates have been considered and in each case, a summary database has been obtained and from which the details of costs and durations for the various methods have been obtained and are shown in Tables 7.6 to 7.13.

### 7.3.2 Results Tables

Where the "method" in Tables 7.1 to 7.5 is marked with an asterisk, e.g. L.I*, it means that for that particular task, no equipment combinations suit the given description for the marked method and the cost and duration data filled in that method is the same data for the method closest in description e.g. L.I and I.L are substituted for one another in such a case and I.C with C.I. This is meant to facilitate better comparison of the various methods for each project.

Where three of the methods are marked with an asterisk for one task, it implies that that particular task can be carried out by only one method (one without asterisk) e.g. Task number 4 in Table 7.2 can only be executed by capital intensive methods and data for all the other methods for that task is the same as that for the C.I method.

#### Summary Tables

Shown in Tables 7.6 to 7.13 are the durations and costs of the various methods of construction at market and various shadow rates. The costs and durations of the various methods are expressed as a percentage of the capital intensive values to facilitate comparison.

TABLE 7.1 The Gravel Road Project: Earthworks

| Task | Quantity | Method | Duration and Cost Based on least Drtn | | Duration and Cost Based on Least Cost | |
|---|---|---|---|---|---|---|
| | | | Drtn(Hrs) | Cost(KSh) | Drtn(Hrs) | Cost(KSh) |
| 1 Grubbing and top soil stripping | 18000 Sq.m | L.I | 48 | 9922 | 48 | 9922 |
| | | I.L* | 48 | 9922 | 48 | 9922 |
| | | I.C* | 50 | 44240 | 50 | 44240 |
| | | C.I | 50 | 44240 | 50 | 44240 |
| 2 Excavate and haul 200m | 2500 Cu.m | L.I | 79 | 118273 | 79 | 118273 |
| | | I.L | 71 | 212727 | 79 | 121868 |
| | | I.C | 29 | 98071 | 29 | 98071 |
| | | C.I | 29 | 112514 | 29 | 112514 |
| 3 Excavate and haul 1000m | 9000 Cu.m | L.I* | 257 | 765818 | 257 | 765818 |
| | | I.L | 257 | 765818 | 257 | 765818 |
| | | I.C | 105 | 353056 | 105 | 353056 |
| | | C.I | 105 | 405050 | 105 | 405050 |
| TOTALS | | L.I | 384 | 894013 | 384 | 894013 |
| | | I.L | 376 | 988467 | 384 | 897608 |
| | | I.C | 184 | 495367 | 184 | 495367 |
| | | C.I | 184 | 561804 | 184 | 561804 |

TABLE 7.2 The Three Storeyed Building Project: Earthworks

| Task | Quantity | Method | Duration and Cost Based on least Drtn | | Duration and Cost Based on Least Cost | |
|---|---|---|---|---|---|---|
| | | | Drtn(Hrs) | Cost(KSh) | Drtn(Hrs) | Cost(KSh) |
| 1 Grubbing and top soil stripping | 1780 Sq.m | L.I | 7 | 965 | 7 | 965 |
| | | I.L* | 7 | 965 | 7 | 965 |
| | | I.C* | 5 | 4371 | 5 | 4371 |
| | | C.I | 5 | 4371 | 5 | 4371 |
| 2 Excavate over site upto 200mm and haul 200m | 356 Cu.m | L.I | 10 | 387506 | 11 | 12928 |
| | | I.L | 10 | 387506 | 11 | 12928 |
| | | I.C | 4 | 5858 | 11 | 3740 |
| | | C.I | 4 | 11507 | 4 | 11507 |
| 3 Excavate to level and haul upto 200m | 890 Cu.m | L.I | 28 | 32317 | 28 | 32317 |
| | | I.L | 25 | 968765 | 25 | 968765 |
| | | I.C | 10 | 14645 | 28 | 9351 |
| | | C.I | 10 | 28768 | 10 | 28768 |
| 4 Excavate trench and stockpile on sides | 1690 Cu.m | L.I* | 20 | 17249 | 20 | 17249 |
| | | I.L* | 20 | 17249 | 20 | 17249 |
| | | I.C* | 20 | 17249 | 20 | 17249 |
| | | C.I | 20 | 17249 | 20 | 17249 |
| TOTALS | | L.I | 65 | 438037 | 66 | 63459 |
| | | I.L | 62 | 1374485 | 63 | 999907 |
| | | I.C | 39 | 42123 | 64 | 34711 |
| | | C.I | 39 | 61895 | 39 | 61895 |

TABLE 7.3 The Oxidation Ponds Project: Earthworks

| Task | Quantity | Method | Duration and Cost Based on least Drtn | | Duration and Cost Based on Least Cost | |
|---|---|---|---|---|---|---|
| | | | Drtn(Hrs) | Cost(KSh) | Drtn(Hrs) | Cost(KSh) |
| 1 Grubbing and top soil stripping | 20400 Sq.m | L.I | 27 | 5581 | 27 | 5581 |
| | | I.L* | 27 | 5581 | 27 | 5581 |
| | | I.C* | 19 | 50033 | 19 | 50033 |
| | | C.I | 19 | 50033 | 19 | 50033 |
| 2 Excavate over site upto 200mm and haul 1500m | 4080. Cu.m | L.I* | 27 | 187768 | 27 | 187768 |
| | | I.L | 27 | 187768 | 27 | 187768 |
| | | I.C | 27 | 171835 | 27 | 171835 |
| | | C.I | 16 | 131880 | 16 | 131880 |
| 3 Excavate and haul 175m | 20000 Cu.m | L.I | 133 | 653600 | 133 | 653600 |
| | | I.L | 133 | 920432 | 133 | 920432 |
| | | I.C | 78 | 579035 | 131 | 574721 |
| | | C.I | 78 | 646470 | 78 | 646470 |
| 4 Excavate and haul 2000m | 7932 Cu.m | L.I* | 63 | 434886 | 63 | 434886 |
| | | I.L | 63 | 434886 | 63 | 434886 |
| | | I.C | 63 | 385629 | 63 | 385629 |
| | | C.I | 31 | 256390 | 31 | 256390 |
| TOTALS | | L.I | 250 | 1281835 | 250 | 1281835 |
| | | I.L | 250 | 1548667 | 250 | 1548667 |
| | | I.C | 187 | 1186532 | 240 | 1182218 |
| | | C.I | 144 | 1084773 | 144 | 1084773 |

TABLE 7.4   The Three Storeyed Building Project: Concreteworks

| Task | Quantity | Method | Duration and Cost Based on least Drtn | | Duration and Cost Based on Least Cost | |
|---|---|---|---|---|---|---|
| | | | Drtn(Hrs) | Cost(KSh) | Drtn(Hrs) | Cost(KSh) |
| 1 Blinding concrete | 86 Cu.m | L.I | 12 | 14464 | 12 | 14464 |
| | | I.L* | 12 | 14464 | 12 | 14464 |
| | | I.C | 8 | 10786 | 8 | 10786 |
| | | C.I* | 8 | 10786 | 8 | 10786 |
| 2 Concrete foundtn strip | 340 Cu.m | L.I | 49 | 57183 | 49 | 57183 |
| | | I.L* | 49 | 57183 | 49 | 57183 |
| | | I.C | 30 | 42643 | 30 | 42643 |
| | | C.I* | 30 | 42643 | 30 | 42643 |
| 3 Concrete ground floor slab | 170 Cu.m | L.I | 24 | 28592 | 24 | 28592 |
| | | I.L* | 24 | 28592 | 24 | 28592 |
| | | I.C | 15 | 21321 | 15 | 21321 |
| | | C.I* | 15 | 21321 | 15 | 21321 |
| 4 Concrete other floor slabs, beams and stairs | 687 Cu.m | L.I | 98 | 115544 | 98 | 115544 |
| | | I.L | 61 | 101337 | 61 | 101337 |
| | | I.C | 61 | 86163 | 61 | 86163 |
| | | C.I | 164 | 311959 | 164 | 311959 |
| TOTALS | | L.I | 183 | 215783 | 183 | 215783 |
| | | I.L | 146 | 201576 | 146 | 201576 |
| | | I.C | 114 | 160913 | 114 | 160913 |
| | | C.I | 217 | 386709 | 217 | 386709 |

TABLE 7.5 The Oxidation Ponds Project: Concreteworks

| Task | Quantity | Method | Duration and cost Based on least Drtn | | Duration and cost Based on Least Cost | |
|---|---|---|---|---|---|---|
| | | | Drtn(Hrs) | Cost(KShs) | Drtn(Hrs) | Cost(KShs) |
| 1 Concrete floor and sides of ponds | 803 Cu.m | L.I | 115 | 135053 | 115 | 135053 |
| | | I.L* | 115 | 135053 | 115 | 135053 |
| | | I.C* | 72 | 100712 | 72 | 100712 |
| | | C.I | 72 | 100712 | 72 | 100712 |
| TOTALS | | L.I | 115 | 135053 | 115 | 132116 |
| | | I.L | 115 | 135053 | 115 | 132116 |
| | | I.C | 72 | 100712 | 72 | 100712 |
| | | C.I | 72 | 100712 | 72 | 100712 |

TABLE 7.6 The Gravel Road Project: Earthworks
Comparison of costs and durations at various shadow rates for different construction methods based on least duration options

| | | CONSTRUCTION METHOD | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| SRR: | SWR | LI<br>Drt: 384<br>%CI Drt: 209 | | IL<br>Drt: 376<br>%CI Drt: 204 | | IC<br>Drt: 184<br>%CI Drt: 100 | | CI<br>Drt: 184<br>%CI Drt: 100 | |
| | | COST | %CI COST | COST | %CI COST | COST | %CI COST | COST | %CI COST |
| 2 | 1.5 | 1346731 | 147 | 1492675 | 163 | 797760 | 87 | 917093 | 100 |
| | 1.1 | 1206765 | 113 | 1361544 | 128 | 771054 | 72.4 | 1064789 | 100 |
| | 1 | 1171663 | 128 | 1328692 | 146 | 764374 | 83.7 | 912715 | 100 |
| | .8 | 1101526 | 121 | 1263004 | 139 | 751020 | 82.4 | 910962 | 100 |
| 1.5 | 1.5 | 1207907 | 163 | 1322563 | 178 | 663082 | 89.4 | 741463 | 100 |
| | 1.1 | 1067941 | 145 | 1191432 | 161 | 636375 | 86.2 | 737960 | 100 |
| | 1 | 1032840 | 140 | 1158582 | 157 | 629695 | 85.5 | 736785 | 100 |
| | .8 | 962704 | 131 | 1092894 | 149 | 616342 | 83.8 | 735332 | 100 |
| 1 | 1.5 | 1069080 | 189 | 1152449 | 204 | 528402 | 93.4 | 565831 | 100 |
| | 1.1 | 929114 | 165 | 1021318 | 182 | 501696 | 89.2 | 562329 | 100 |
| | 1 | 894013 | 159 | 988467 | 176 | 495367 | 88.2 | 561804 | 100 |
| | .8 | 823876 | 147 | 922778 | 165 | 481662 | 86.1 | 559700 | 100 |
| .8 | 1.5 | 1013551 | 205 | 1084404 | 219 | 474533 | 95.8 | 495580 | 100 |
| | 1.1 | 873586 | 178 | 953275 | 194 | 447825 | 91 | 492076 | 100 |
| | 1 | 838484 | 171 | 920423 | 187 | 441145 | 89.8 | 491201 | 100 |
| | .8 | 768348 | 157 | 854735 | 175 | 427791 | 87.4 | 489449 | 100 |

KEY

SRR - Shadow Rental rate Ratio = Shadow Rental Rate/Market Rental Rate

SWR - Shadow Wage rate Ratio = Shadow Wage Rate/Market Wage Rate

Drt - Duration in Hrs

Underlined are the values at Market Rates

TABLE 7.7 The Gravel Road Project: Earthworks
Comparison of costs and durations at various shadow rates for different construction methods based on least cost options

| | | CONSTRUCTION METHOD | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| SRR: | SWR | LI Drt: 384 %CI Drt: 204 | | IL Drt: 384 %CI Drt: 204 | | IC Drt: 203 %CI Drt: 108 | | CI Drt: 188 %CI Drt: 100 | |
| | | COST | %CI COST | COST | %CI COST | COST | %CI COST | COST | %CI COST |
| 2 | 1.5 | 1346731 | 147 | 1359027 | 148 | 797760 | 87 | 917093 | 100 |
| | 1.1 | 1206765 | 135 | 1219023 | 136 | 763709 | 85.2 | 896670 | 100 |
| | 1 | 1171663 | 131 | 1183911 | 133 | 753100 | 84.5 | 891686 | 100 |
| | .8 | 1101526 | 125 | 1113755 | 126 | 731944 | 83 | 881688 | 100 |
| 1.5 | 1.5 | 1207907 | 163 | 1215877 | 164 | 663082 | 89.4 | 741463 | 100 |
| | 1.1 | 1067941 | 145 | 1075872 | 146 | 636375 | 86.3 | 737289 | 100 |
| | 1 | 1032840 | 140 | 1040761 | 141 | 627779 | 85.2 | 737085 | 100 |
| | .8 | 962704 | 131 | 970605 | 132 | 606624 | 82.5 | 735332 | 100 |
| 1 | 1.5 | 1069080 | 189 | 1072724 | 190 | 528402 | 93.4 | 565831 | 100 |
| | 1.1 | 929114 | 165 | 932719 | 166 | 501696 | 89.2 | 562329 | 100 |
| | 1 | 894013 | 159 | 897608 | 160 | 495367 | 88.2 | 561804 | 100 |
| | .8 | 823876 | 147 | 827451 | 148 | 481301 | 86 | 559700 | 100 |
| .8 | 1.5 | 1013551 | 205 | 1015464 | 205 | 474533 | 95.8 | 495580 | 100 |
| | 1.1 | 873586 | 178 | 875460 | 178 | 447825 | 91 | 492076 | 100 |
| | 1 | 838484 | 171 | 840348 | 171 | 441145 | 89.8 | 491201 | 100 |
| | .8 | 768348 | 157 | 770192 | 157 | 427791 | 87.4 | 489449 | 100 |

KEY

SRR - Shadow Rental rate Ratio = Shadow Rental Rate/Market Rental Rate

SWR - Shadow Wage rate Ratio = Shadow Wage Rate/Market Wage Rate

Drt - Duration in Hrs

Underlined are the values at Market Rates

TABLE 7.8 The Three Storeyed Building Project: Earthworks
Comparison of costs and durations at various shadow rates for different construction methods based on least duration options

| | | CONSTRUCTION METHOD | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| SRR: | SWR | LI Drt: 65 %CI Drt: 167 | | IL Drt: 62 %CI Drt: 159 | | IC Drt: 39 %CI Drt: 100 | | CI Drt: 39 %CI Drt: 100 | |
| | | COST | %CI COST | COST | %CI COST | COST | %CI COST | COST | %CI COST |
| 2 | 1.5 | 672539 | 648 | 2102320 | 2027 | 74307 | 71.6 | 103739 | 100 |
| | 1.1 | 623178 | 603 | 1975840 | 1911 | 73467 | 71.1 | 103389 | 100 |
| | 1 | 610814 | 591 | 1944202 | 1882 | 73257 | 70.9 | 103301 | 100 |
| | .8 | 586110 | 568 | 1880949 | 1824 | 72838 | 70.6 | 103127 | 100 |
| 1.5 | 1.5 | 586151 | 706 | 1817462 | 2189 | 58750 | 70.7 | 83046 | 100 |
| | 1.1 | 536790 | 649 | 1690982 | 2045 | 57910 | 70 | 82695 | 100 |
| | 1 | 524426 | 635 | 1659344 | 2009 | 57699 | 69.8 | 82608 | 100 |
| | .8 | 499721 | 606 | 1596090 | 1936 | 57278 | 69.5 | 82432 | 100 |
| 1 | 1.5 | 499763 | 802 | 1532604 | 2458 | 43191 | 69.3 | 62351 | 100 |
| | 1.1 | 450402 | 726 | 1406124 | 2268 | 42351 | 68.3 | 62002 | 100 |
| | 1 | 438037 | 708 | 1374485 | 2221 | 42123 | 68.1 | 61895 | 100 |
| | .8 | 413333 | 673 | 1311232 | 2134 | 41720 | 67.9 | 61448 | 100 |
| .8 | 1.5 | 465207 | 860 | 1418658 | 2624 | 36968 | 68.4 | 54074 | 100 |
| | 1.1 | 415847 | 774 | 1292181 | 2405 | 36128 | 67.2 | 53723 | 100 |
| | 1 | 403482 | 752 | 1260542 | 2350 | 35918 | 67 | 53635 | 100 |
| | .8 | 378777 | 709 | 1197288 | 2240 | 35498 | 66.4 | 53460 | 100 |

KEY

SRR - Shadow Rental rate Ratio = Shadow Rental Rate/Market Rental Rate

SWR - Shadow Wage rate Ratio = Shadow Wage Rate/Market Wage Rate

Drt - Duration in Hrs

Underlined are the values at Market Rates

TABLE 7.9 The Three Storeyed Building Project: Earthworks
Comparison of costs and durations at various shadow rates for different construction methods based on least cost options

| CONSTRUCTION METHOD | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| SRR: | SWR | LI<br>Drt: 66<br>%CI Drt: 169 | | IL<br>Drt: 63<br>%CI Drt: 162 | | IC<br>Drt: 64<br>%CI Drt: 164 | | CI<br>Drt: 39<br>%CI Drt: 100 | |
| | | COST | %CI COST | COST | %CI COST | COST | %CI COST | COST | %CI COST |
| 2 | 1.5 | 100626 | 97 | 1499065 | 1445 | 62985 | 60.7 | 103739 | 100 |
| | 1.1 | 82113 | 79.4 | 1434775 | 1388 | 62689 | 60.6 | 103389 | 100 |
| | 1 | 77459 | 75 | 1410847 | 1366 | 62615 | 60.6 | 103301 | 100 |
| | .8 | 68174 | 66.1 | 1363013 | 1322 | 62466 | 60.6 | 103127 | 100 |
| 1.5 | 1.5 | 93626 | 113 | 1324937 | 1595 | 49044 | 59.1 | 83046 | 100 |
| | 1.1 | 75113 | 90.8 | 1229305 | 1487 | 48747 | 58.9 | 82695 | 100 |
| | 1 | 70459 | 85.3 | 1205377 | 1459 | 48672 | 58.9 | 82608 | 100 |
| | .8 | 61173 | 74.2 | 1157742 | 1404 | 48524 | 58.9 | 82432 | 100 |
| 1 | 1.5 | 86626 | 139 | 1119467 | 1795 | 35100 | 56.3 | 62351 | 100 |
| | 1.1 | 68113 | 110 | 1023835 | 1651 | 34804 | 56.1 | 62002 | 100 |
| | 1 | <u>63459</u> | <u>103</u> | <u>999907</u> | <u>1615</u> | <u>34711</u> | <u>56.1</u> | <u>61895</u> | <u>100</u> |
| | .8 | 54173 | 88.2 | 952072 | 1549 | 34580 | 56.3 | 61448 | 100 |
| .8 | 1.5 | 83826 | 155 | 1037277 | 1918 | 29523 | 54.6 | 54074 | 100 |
| | 1.1 | 65313 | 122 | 941647 | 1753 | 29227 | 54.4 | 53723 | 100 |
| | 1 | 60658 | 113 | 917718 | 1711 | 29152 | 54.4 | 53635 | 100 |
| | .8 | 51373 | 96.1 | 869884 | 1627 | 29003 | 54.3 | 53460 | 100 |

KEY

SRR - Shadow Rental rate Ratio = Shadow Rental Rate/Market Rental Rate

SWR - Shadow Wage rate Ratio = Shadow Wage Rate/Market Wage Rate

Drt - Duration in Hrs

Underlined are the values at Market Rates

TABLE 7.10 The Oxidation Ponds Project: Earthworks
Comparison of costs and durations at various shadow rates for different construction methods based on least duration options

| | | CONSTRUCTION METHOD | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| SRR: | SWR | LI<br>Drt: 250<br>%CI Drt: 219 | | IL<br>Drt: 250<br>%CI Drt: 219 | | IC<br>Drt: 187<br>%CI Drt: 164 | | CI<br>Drt: 114<br>%CI Drt: 100 | |
| | | COST | %CI COST | COST | %CI COST | COST | %CI COST | COST | %CI COST |
| 2 | 1.5 | 1933659 | 111 | 2351027 | 135 | 1920495 | 110 | 1746040 | 100 |
| | 1.1 | 1557400 | 89.5 | 2068184 | 119 | 1846815 | 106 | 1739211 | 100 |
| | 1 | 1462862 | 84.2 | 1997294 | 115 | 1828389 | 105 | 1737504 | 100 |
| | .8 | 1274192 | 73.5 | 1855532 | 107 | 1791546 | 103 | 1734087 | 100 |
| 1.5 | 1.5 | 1843146 | 130 | 2126714 | 150 | 1599566 | 113 | 1419634 | 100 |
| | 1.1 | 1466886 | 104 | 1843870 | 131 | 1525888 | 108 | 1412846 | 100 |
| | 1 | 1372348 | 97.3 | 1772980 | 126 | 1507460 | 107 | 1411138 | 100 |
| | .8 | 1183679 | 84.1 | 1631219 | 116 | 1470619 | 104 | 1407721 | 100 |
| 1 | 1.5 | 1752633 | 160 | 1902401 | 174 | 1278638 | 117 | 1093308 | 100 |
| | 1.1 | 1376374 | 127 | 1619558 | 149 | 1204958 | 111 | 1086477 | 100 |
| | 1 | 1281835 | 118 | 1548667 | 143 | 1186532 | 109 | 1084773 | 100 |
| | .8 | 1093166 | 101 | 1406906 | 130 | 1149690 | 106 | 1081355 | 100 |
| .8 | 1.5 | 1716428 | 178 | 1812676 | 188 | 1150267 | 119 | 962762 | 100 |
| | 1.1 | 1340168 | 140 | 1529836 | 160 | 1076588 | 113 | 955933 | 100 |
| | 1 | 1245630 | 131 | 1458942 | 153 | 1058161 | 111 | 954229 | 100 |
| | .8 | 1056961 | 111 | 1317181 | 139 | 1021319 | 107 | 950810 | 100 |

KEY

SRR - Shadow Rental rate Ratio = Shadow Rental Rate/Market Rental Rate

SWR - Shadow Wage rate Ratio = Shadow Wage Rate/Market Wage Rate

Drt - Duration in Hrs

Underlined are the values at Market Rates

TABLE 7.11 The Oxidation Ponds Project: Earthworks
Comparison of costs and durations at various shadow rates for different construction methods based on least cost options

| CONSTRUCTION METHOD | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| SRR: | SWR | LI<br>Drt: 250<br>%CI Drt: 174 | | IL<br>Drt: 250<br>%CI Drt: 174 | | IC<br>Drt: 240<br>%CI Drt: 167 | | CI<br>Drt: 144<br>%CI Drt: 100 | |
| | | COST | %CI COST | COST | %CI COST | COST | %CI COST | COST | %CI COST |
| 2 | 1.5 | 1933659 | 111 | 2351027 | 135 | 1903991 | 109 | 1746040 | 100 |
| | 1.1 | 1557400 | 89.5 | 2068184 | 119 | 1715831 | 98.7 | 1739211 | 100 |
| | 1 | 1462862 | 84.1 | 1997294 | 115 | 1668493 | 95.9 | 1739211 | 100 |
| | .8 | 1274192 | 73.5 | 1855532 | 107 | 1574214 | 90.8 | 1734087 | 100 |
| 1.5 | 1.5 | 1843146 | 130 | 2126714 | 150 | 1599566 | 113 | 1419634 | 100 |
| | 1.1 | 1466886 | 104 | 1843870 | 131 | 1472693 | 104 | 1412846 | 100 |
| | 1 | 1372348 | 97.3 | 1772980 | 126 | 1425355 | 101 | 1411138 | 100 |
| | .8 | 1183679 | 84.1 | 1631219 | 116 | 1331078 | 94.6 | 1407721 | 100 |
| 1 | 1.5 | 1752633 | 160 | 1902401 | 174 | 1278638 | 117 | 1093308 | 100 |
| | 1.1 | 1376374 | 127 | 1619558 | 149 | 1204958 | 111 | 1086477 | 100 |
| | 1 | <u>1281835</u> | <u>118</u> | <u>1548667</u> | <u>143</u> | <u>1182218</u> | <u>109</u> | <u>1084773</u> | <u>100</u> |
| | .8 | 1093166 | 101 | 1406906 | 130 | 1087940 | 101 | 1081355 | 100 |
| .8 | 1.5 | 1716428 | 178 | 1812676 | 188 | 1150267 | 119 | 962762 | 100 |
| | 1.1 | 1340168 | 140 | 1529836 | 160 | 1076588 | 113 | 955933 | 100 |
| | 1 | 1245630 | 131 | 1458942 | 153 | 1058161 | 111 | 954229 | 100 |
| | .8 | 1056961 | 111 | 1317181 | 139 | 990685 | 104 | 950810 | 100 |

KEY

SRR - Shadow Rental rate Ratio = Shadow Rental Rate/Market Rental Rate

SWR - Shadow Wage rate Ratio = Shadow Wage Rate/Market Wage Rate

Drt - Duration in Hrs

Underlined are the values at Market Rates

TABLE 7.12 The Three Storeyed Building Project: Concreteworks
Comparison of costs and durations at various shadow rates
for different construction methods
Material cost is KSh
1853805

| CONSTRUCTION METHOD | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SRR: | SWR | LI<br>Drt: 183<br>%CI Drt: 84.3 | | | | IL<br>Drt: 146<br>%CI Drt: 67.3 | | | | IC<br>Drt: 114<br>%CI Drt: 52.5 | | | | CI<br>Drt: 217<br>%CI Drt: 100 | | | |
| | | COST EXC MAT | %CI COST | COST INC MAT | %CI COST | COST EXC MAT | %CI COST | COST INC MAT | %CI COST | COST EXC MAT | %CI COST | COST INC MAT | %CI COST | COST EXC MAT | %CI COST | COST INC MAT | %CI COST |
| 2 | 1.5 | 399024 | 56 | 2252829 | 87.8 | 369446 | 51.8 | 2223251 | 86.6 | 292478 | 41 | 2146283 | 83.6 | 712981 | 100 | 2566786 | 100 |
| | 1.1 | 383808 | 54.9 | 2237613 | 87.7 | 357491 | 51.2 | 2211296 | 86.6 | 285271 | 40.8 | 2139076 | 83.8 | 698816 | 100 | 2552621 | 100 |
| | 1 | 379992 | 54.7 | 2233797 | 87.6 | 354497 | 51 | 2208302 | 86.6 | 283470 | 40.8 | 2137275 | 83.8 | 695276 | 100 | 2549081 | 100 |
| | .8 | 372371 | 54.1 | 2226176 | 120 | 348512 | 50.6 | 2202317 | 119 | 279863 | 40.7 | 2133668 | 115 | 688187 | 100 | 1854204 | 100 |
| 1.5 | 1.5 | 316919 | 56.7 | 2170724 | 90 | 292985 | 52.4 | 2146790 | 89 | 231197 | 41.4 | 2085002 | 86.4 | 558696 | 100 | 2412501 | 100 |
| | 1.1 | 301702 | 55.4 | 1843870 | 76.9 | 281029 | 51.6 | 2134834 | 89 | 223990 | 41.1 | 2077795 | 86.6 | 544531 | 100 | 2398336 | 100 |
| | 1 | 297887 | 55.1 | 1772980 | 74 | 278036 | 51.4 | 2131841 | 89 | 222189 | 41.1 | 2075994 | 86.7 | 540991 | 100 | 2394796 | 100 |
| | .8 | 290267 | 54.4 | 1631219 | 68.3 | 272052 | 51 | 2125857 | 89 | 218583 | 40.9 | 2072388 | 86.8 | 533903 | 100 | 2387708 | 100 |
| 1 | 1.5 | 234822 | 58.1 | 1902401 | 84.2 | 216530 | 53.5 | 2070335 | 91.7 | 169923 | 42 | 2023728 | 89.6 | 404421 | 100 | 2258226 | 100 |
| | 1.1 | 219605 | 56.3 | 1619558 | 72.2 | 204575 | 52.4 | 2058380 | 91.7 | 162715 | 41.7 | 2016520 | 89.9 | 390256 | 100 | 2244061 | 100 |
| | 1 | <u>215783</u> | <u>55.8</u> | <u>1548667</u> | <u>69.1</u> | <u>201576</u> | <u>52.1</u> | <u>2055381</u> | <u>91.7</u> | <u>160913</u> | <u>41.6</u> | <u>2014718</u> | <u>89.9</u> | <u>386709</u> | <u>100</u> | <u>2240514</u> | <u>100</u> |
| | .8 | 208169 | 54.8 | 1406906 | 63 | 195596 | 51.5 | 2049401 | 91.8 | 157303 | 41.4 | 2011108 | 90 | 379625 | 100 | 2233430 | 100 |
| .8 | 1.5 | 201984 | 58.9 | 1812676 | 82.5 | 185950 | 54.3 | 2039755 | 92.9 | 145414 | 42.4 | 1999219 | 91 | 342713 | 100 | 2196518 | 100 |
| | 1.1 | 186768 | 56.8 | 1529836 | 70.1 | 173994 | 53 | 2027799 | 92.9 | 138207 | 42.1 | 1992012 | 91.3 | 328548 | 100 | 2182353 | 100 |
| | 1 | 182952 | 56.3 | 1458942 | 67 | 171000 | 52.6 | 2024805 | 92.9 | 136405 | 42 | 1990210 | 91.3 | 325007 | 100 | 2178812 | 100 |
| | .8 | 175331 | 55.1 | 1317181 | 60.7 | 165015 | 51.9 | 2018820 | 93 | 132799 | 41.8 | 1986604 | 91.5 | 317920 | 100 | 2171725 | 100 |

KEY

SRR - Shadow Rental rate Ratio = Shadow Rental Rate/Market Rental Rate

SWR - Shadow Wage rate Ratio = Shadow Wage Rate/Market Wage Rate

Drt - Duration in Hrs

EXC MAT - Excluding Materials cost

INC MAT - Including Materials cost

Underlined are the values at Market Rates

TABLE 7.13 The Oxidation Ponds Project: Concreteworks
Comparison of costs and durations at various shadow rates
for different construction methods
Material Cost is KSh.
898075

| | | CONSTRUCTION METHOD | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SRR: | SWR | LI<br>Drt: 115<br>%CI Drt: 160 | | | | IL<br>Drt: 115<br>%CI Drt: 160 | | | | IC<br>Drt: 72<br>%CI Drt: 100 | | | | CI<br>Drt: 72<br>%CI Drt: 100 | | | |
| | | COST EXC MAT | %CI COST | COST INC MAT | %CI COST | COST EXC MAT | %CI COST | COST INC MAT | %CI COST | COST EXC MAT | %CI COST | COST INC MAT | %CI COST | COST EXC MAT | %CI COST | COST INC MAT | %CI COST |
| 2 | 1.5 | 249740 | 136 | 1147815 | 106 | 249740 | 136 | 1147815 | 106 | 183055 | 100 | 1081130 | 100 | 183055 | 100 | 1081130 | 100 |
| | 1.1 | 240216 | 135 | 1138291 | 106 | 240216 | 135 | 1138291 | 106 | 178544 | 100 | 1076619 | 100 | 178544 | 100 | 1076619 | 100 |
| | 1 | 237828 | 134 | 1135903 | 106 | 237828 | 134 | 1135903 | 106 | 177417 | 100 | 1075492 | 100 | 177417 | 100 | 1075492 | 100 |
| | .8 | 233058 | 133 | 1131133 | 105 | 233058 | 133 | 1131133 | 105 | 175160 | 100 | 1073235 | 100 | 175160 | 100 | 1073235 | 100 |
| 1.5 | 1.5 | 198352 | 137 | 1096427 | 105 | 198352 | 137 | 1096427 | 105 | 144701 | 100 | 1042776 | 100 | 144701 | 100 | 1042776 | 100 |
| | 1.1 | 188829 | 135 | 1086904 | 105 | 188829 | 135 | 1086904 | 105 | 140190 | 100 | 1038265 | 100 | 140190 | 100 | 1038265 | 100 |
| | 1 | 186441 | 134 | 1086904 | 105 | 186441 | 134 | 1086904 | 105 | 139063 | 100 | 1037138 | 100 | 139063 | 100 | 1037138 | 100 |
| | .8 | 181671 | 133 | 1079746 | 104 | 181671 | 133 | 1079746 | 104 | 136806 | 100 | 1034881 | 100 | 136806 | 100 | 1034881 | 100 |
| 1 | 1.5 | 146970 | 138 | 1045045 | 104 | 146970 | 138 | 1045045 | 104 | 106351 | 100 | 1004426 | 100 | 106351 | 100 | 1004426 | 100 |
| | 1.1 | 137446 | 135 | 1035521 | 104 | 137446 | 135 | 1035521 | 104 | 101840 | 100 | 999915 | 100 | 101840 | 100 | 999915 | 100 |
| | 1 | <u>135053</u> | <u>134</u> | <u>1033128</u> | <u>103</u> | <u>135053</u> | <u>134</u> | <u>1033128</u> | <u>103</u> | <u>100712</u> | <u>100</u> | <u>998787</u> | <u>100</u> | <u>100712</u> | <u>100</u> | <u>998787</u> | <u>100</u> |
| | .8 | 130288 | 132 | 1028363 | 103 | 130288 | 132 | 1028363 | 103 | 98456 | 100 | 996531 | 100 | 98456 | 100 | 996531 | 100 |
| .8 | 1.5 | 126417 | 139 | 1024492 | 104 | 126417 | 139 | 1024492 | 104 | 91011 | 100 | 989086 | 100 | 91011 | 100 | 989086 | 100 |
| | 1.1 | 116894 | 135 | 1014969 | 103 | 116894 | 135 | 1014969 | 103 | 86500 | 100 | 984575 | 100 | 86500 | 100 | 984575 | 100 |
| | 1 | 114506 | 134 | 1012581 | 103 | 114506 | 134 | 1012581 | 103 | 85373 | 100 | 983448 | 100 | 85373 | 100 | 983448 | 100 |
| | .8 | 109736 | 132 | 1007811 | 103 | 109736 | 132 | 1007811 | 103 | 83116 | 100 | 981191 | 100 | 83116 | 100 | 981191 | 100 |

KEY

SRR - Shadow Rental rate Ratio = Shadow Rental Rate/Market Rental Rate

SWR - Shadow Wage rate Ratio = Shadow Wage Rate/Market Wage Rate

Drt - Duration in Hrs

EXC MAT - Excluding Materials cost

INC MAT - Including Materials cost

Underlined are the values at Market Rates

## 7.4 INDIVIDUAL PROJECTS DISCUSSION

### 7.4.1 The Gravel Road Project

(a) Based on Least Duration Options

(i) At Market Rates

Table 7.6 shows that the CI and IC methods of construction take the same duration of 184 hours to carry out the earthworks and the IL method takes 104% longer (i.e. twice the duration) time than the CI method and the LI method takes 109% longer duration than the CI method. The IC method results in costs that are 88% of the CI method costs resulting to a saving of KSh.66437. This makes the IC method the most preferred option for earthworks in this project because it costs lowest and takes the least duration. The most expensive method is the IL method with the cost being 76% higher than the CI cost.

(ii) At Shadow Rates

A reference to Table 7.6 shows that as shadow rental rate (SRR) is increased at a constant shadow wage rate (SWR), the difference in cost between LI method and CI method decreases. For example, with SWR equal to the market rate and SRR increasing from 1 to 2.0, the LI cost changes from 159% of CI cost to 128% of CI cost respectively. This is due to the high effect of SRR on the equipment based methods. However, the IC method cost does not change much varying only from 88% of CI cost at SRR = 1.0 and SWR = 1.0 to 84% at SRR = 2.0 and SWR = 1.0.

Within the limits of the SRR possibilities investigated, the IC method results in the least cost and at a duration equal to the CI duration thus making this method the best option for the Gravel Road project.

(b) Based on Least Cost Options

(i) At Market Rates

Table 7.7 taken in conjunction with Table 7.6 shows that there is not much difference between the least cost options and the least duration options. The only noticeable difference is in the IL method which costs 60% more than the CI cost (based on least cost option) compared to 76% of CI cost when considered under least duration options. The best option however, remains the IC method with cost at 88% of the CI cost even though the duration is 8% longer than the CI duration.

(ii) At Shadow Rates

As in the least cost option, the IC method remains the best option for the gravel road project earthworks.

(c) Implication of Results

Earthworks for the gravel road project is best carried out by the IC method of construction i.e methods that incorporate use of equipment for some activities and use of unskilled labour in others.

7.4.2 A; The 3 Storeyed Building Project: Earthworks

(a) Based on Least Duration Options

Results presented in Table 7.8 show that the CI and IC methods take the same duration of 39 hours to carry out the earthworks which is mainly excavation to required levels and hauling of excavated material. The IL and LI methods take 59% and 67% longer than the CI method respectively for the same job.

Within the least duration options, the IC method costs least at 68% of the CI method cost thus making it the best option.

(b) Based on Least Cost Options

(i) At Market Rates

At market rates, though taking 64% of the CI duration, the IC method costs least at 56% of the CI cost. LI method costs about twice as much as the CI method and takes about one and a half times the CI duration. This then implies that the LI method would be a viable option alongside the IC method if the selection of method is based on least cost. The most expensive method remains the IL method with cost being 1615% of the CI method.

(ii) At Shadow Rates

At high shadow rental rates and low shadow wage rates, the LI method costs less than the CI method with the cost ranging from 66% to 96% of the CI cost. The duration, however, remains 69% higher than the CI method. The IC method remains the lowest cost method with cost ranging from 56% to 61% of the CI cost.

c) Implication of Results

At market and shadow rates, the IC method is the best method of construction whether selection is based on least cost or least duration. The LI method should be considered when analysis is carried out at high shadow rental rates.

Shadow rental rates are likely to be high in situations where equipment utilisation rates are low. This may be a result of their inappropriate use, breakdowns and shortage of adequate maintenance facilities in addition to shortage of foreign exchange with which to buy adequate parts.

7.4.2 B: The 3 Storeyed Building Project: Concreteworks

(i) At Market Rates

Results in Table 7.12 show that at market rates and excluding the materials costs, the IC method is the least expensive method of construction costing just less than half of the corresponding CI cost (42% of CI cost). The LI method costs just slightly over over half of the CI cost (56% of CI cost).

However, when the cost of materials is included, the order of preference of methods is; (1) LI costing 69% of CI cost, (2) IC method costing 90% of CI cost, (3) IL method at a cost of 92% of CI cost and (4) CI cost, if selection is based on cost.

This shows that materials costs can have an effect on method selection and need to be included in the analysis.

(ii) At Shadow Rates

At high SRR, high SWR and with materials cost included in the total cost, the lowest cost method is the IC method at 84% of the CI cost followed closely by the LI method at 88% of the CI cost. The third preferred method is the IL method at 92% of the CI cost.

With materials being included when analysing at shadow rates, the order of preference of methods changes and the lowest cost method becomes the IC method of construction.

(iii) Implication of Results

Concreteworks for the three storeyed building project are best carried out by IC methods with LI methods following closely in cost to the IC methods regardless of whether decision is made at shadow or market rates. The IC method of concreting includes moving concrete by use of a concrete pump. The most expensive method of concreting is the CI method characterised by moving and placing concrete by use of a crane and skip.

The results have also shown the significance of including materials cost in the analysis.

7.4.3 A: The Oxidation Ponds Project: Earthworks

a) Based on Least Duration Options

(i) At Market Rates

The CI method results in the lowest duration of 114 Hrs and also costs the least (Table 7.10). The IC method is closest in cost at 109% of the CI cost though the duration is 64% longer than the CI duration. The LI method is third in preference at 18% higher in cost than the CI method and a duration of 219% of the CI duration.

The least preferred method is the IL method at a cost of 43% higher than the CI cost and a duration of 74% longer than the CI duration.

(ii) At Shadow Rates

At high SRR and high SWR, the best method remains the CI method with IC following at a cost of 110% of the CI cost and the LI method at a cost of 111% of CI cost being another option. However, at high SRR and SWR equal to market rate, the LI method costs least ranging from 84% to 97% of the CI cost.

Carrying out analysis at high SRR and high SWR results to preference of labour based methods.

(b) Based on Least Cost Options

(i) At Market Rates

The method most preferred at market rates is the CI method followed by the IC method at twice the CI cost (Table 7.11). The LI method comes third in preference with cost at 18% higher than the CI cost and taking 74% longer to complete the work. The least preferred method is the IL method at a cost of 143% of the CI cost and a duration that is 74% longer than the CI duration.

(ii) At Shadow Rates

At high SRR and high SWR, the best method is the CI method. However, at SWR equal to the market rate and SRR higher than the market rate, the LI method costs lowest than all the other methods.

(c) Implication of Results

At market rates, the CI method of carrying out earthworks is the best option whether selection is based on least cost or least duration. However, at high SRR and with SWR equal to the market rates, the LI method costs least though taking longer than other methods to carry out the works.

7.4.3 B: The Oxidation Ponds Project: Concreteworks

(a) Alternative 1: In Situ Concrete

(i) At Market Rates

Table 7.13 shows that at market rates, the IC and CI methods are the least cost methods and also take the shortest duration. With material costs included, the IL and LI methods are only 3% higher in cost than the CI method though they result to a duration of 60% higher than the CI method.

(ii) At Shadow Rates

With both SRR and SWR being greater than market rates, the CI and IC methods still remain the better choice of method. Whatever combination of SWR and SRR ratios is considered, the IC and CI methods remain the best choice costwise and durationwise.

(iii) Implication of Results

Concreting for the Oxidation Ponds Project is best carried out by IC (or CI) methods. The notable feature of this method is that concrete is moved and placed by use of a concrete pump.

(b) Alternative 2: Pre-cast Concrete Units (PC units)

This alternative involves placing of PC units (600 by 600 by 50mm) on the floor and sides of the oxidation ponds. It is assumed that the precast units are stockpiled very close to the placing point thus eliminating the need for further hauling.

Total area to be covered = 16046 sq.m

Total Number of units required = 16046/(0.6 x 0.6) = 44572

Assuming a supply rate of 1000 units/day,

Time required to supply all = 45 days

Construction Method

Due to the nature of the activity of placing PC units, the only method considered viable is the Labour Intensive method and is the one considered in this alternative.

For placing, a gang of 1 unskilled labourer and 2 skilled labourers (masons) results to a productivity of 1.67 sq.m/hr per mason (ENTERKIN and REYNOLDS, 1978). With this output, 7 unskilled labourers with 14 masons for each one of the three ponds results to a total duration of;

Duration = 16046/(1.67 x 14 x 3) = 229 Hrs.

Market Rates

At market rates, the cost of laying 600 by 600 by 50mm PC units is KSh 120.00/sq.m.

Hence;

Total Cost = 16046 x 120 = KSh 1925520.00

Implication of Results

Concreting of oxidation ponds by in-situ concrete costs less than concreting by use of pre-cast slab units. This is arrived at by comparing the costs of the two alternative methods at market rates. Though there has been no analysis done for alternative 2 at shadow rates, it is still evident that the best method of concreting the ponds is by IC (or CI) in-situ concreting as this method not only costs less but also takes the shortest time.

## 7.5 DISCUSSION OF OVERALL RESULTS

Table 7.14 shown below gives a summary of the results from the individual projects as discussed in previous sections. The number shown indicates the order of preference of a particular method for each project. 1 indicates first preference and 4 indicates least preferred method.

ABLE 7.14 Summary of Results: Order of Preference of Methods
Based on Lowest Cost and Shortest Duration

| Project | SRR = 1.0<br>SWR = 1.0 | | | | SRR > 1.0<br>SWR = 1.0 | | | | SRR > 1.0<br>SWR < 1.0 | | | | SRR < 1.0<br>SWR < 1.0 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | LI | IL | IC | CI | LI | IL | IC | CI | LI | IL | IC | CI | LI | IL | IC | CI |
| The Gravel Road Project<br>Least Duration Option | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 |
| The Gravel Road Project<br>Least Cost Option | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 |
| Bldg. Proj. Earthworks<br>Least Duration Option | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 |
| Bldg. Proj. Earthworks<br>Least Cost Option | 3 | 4 | 1 | 2 | 2 | 4 | 1 | 3 | 2 | 4 | 1 | 3 | 3 | 4 | 1 | 2 |
| Bldg. Proj. Concworks | 1 | 3 | 2 | 4 | 3 | 2 | 1 | 4 | 1 | 3 | 2 | 4 | 1 | 3 | 2 | 4 |
| Oxid. Proj. Earthworks<br>Least Duration Option | 3 | 4 | 2 | 1 | 1 | 4 | 3 | 2 | 1 | 3 | 2 | 4 | 3 | 4 | 2 | 1 |
| Oxid. Proj. Earthworks<br>Least Cost Option | 3 | 4 | 2 | 1 | 1 | 4 | 3 | 2 | 1 | 4 | 2 | 3 | 3 | 4 | 2 | 1 |
| Oxid. Proj. concworks<br>Alternative 1 | 2 | 2 | 1 | 1 | 2 | 2 | 1 | 1 | 2 | 2 | 1 | 1 | 2 | 2 | 1 | 1 |
| Oxid. Proj. Concworks<br>Alternative 2 | 1 | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |

KEY

SRR - Shadow Rental rate Ratio = Shadow rental rate/Market rental rate

SWR - Shadow Wage rate Ratio = Shadow wage rate/Market wage rate

NA - Not Applicable

### 7.5.1 Market Rates

A reference to Table 7.14 shows that at market rates, the most preferred method of construction is the Intermediate C method for the Gravel Road Project earthworks as well as for the Three Storeyed Building project earthworks. This method allows utilisation of both equipment and labour. Capital Intensive methods are the best option for all the concreteworks and for the Oxidation Ponds project earthworks.

### 7.5.2 Shadow Rates

At shadow rates, the situation remains as at market rates for the Gravel Road project and the Three Storeyed Building project earthworks. However, for the Oxidation Ponds Project earthworks, the best method of construction is the LI method when SWR is less than market rates and SRR greater than market rates.

## 7.6 SENSITIVITY ANALYSIS

### 7.6.1 General

There is always an element of uncertainty involved in both cost and productivity estimates in the construction industry.The possible variations in these factors can have a great effect on project costs and durations. This therefore emphasizes the need to consider the changes likely to be caused by such variations in assessing the best method to be used in construction.

A sensitivity analysis is presented in this section.

### 7.6.2 Variables Selected

While there is a wide range of factors that can affect the projects costs and durations, the unit costs of the factor inputs are used here to demonstrate how sensitivity analysis can be carried out.

Though there are several factors that make up the cost of the inputs, the ones isolated for this study are;

(i) Fuel Cost
(ii) Skilled Labour Cost
(iii) Unskilled Labour Cost
(iv) Equipment Rental Rate

The analysis has only been carried out for the Oxidation Ponds Project earthworks to illustrate the method of sensitivity analysis. The same procedure can be followed for any other project and also for any other variable.

### 7.6.3 The Method of Carrying Out Sensitivity Analysis

Calculations have been done to determine the effects of data inaccuracy on the estimate of the market unit rates of the four factors mentioned above. Effects of variations ranging from -33% to 50% in the unit rates of fuel, skilled labour, unskilled labour and equipment rental have been investigated. The costs of the various methods of construction have been calculated as previously shown in Chapter 6.

TABLE 7.15 The effect on cost of decreasing the cost of Fuel, Skilled Labour, Unskilled Labour and Equipment Rental by 33%

| METHOD | PARTICULARS | CURRENT ESTIMATE | FUEL COST | SKLD LB COST | UNSKLD LB COST | EQUIP RENTAL |
|---|---|---|---|---|---|---|
| LI | a. New Cost (NC) | 1281835 | 1229646 | 1279489 | 973293 | 1222096 |
| | b. NC as %age of Current Estimate | 100 | 96 | 100 | 76 | 95 |
| | c. NC as %age of New CI cost | 118 | 130 | 119 | 90 | 141 |
| | d. Rank of method | [3] | 3 | 3 | *1 | 3 |
| IL | a. New Cost (NC) | 1548667 | 1419330 | 1542853 | 1321053 | 1400620 |
| | b. NC as %age of Current Estimate | 100 | 92 | 100 | 85 | 90 |
| | c. NC as %age of New CI cost | 143 | 150 | 143 | 122 | 161 |
| | d. Rank of method | 4 | 4 | 4 | 4 | 4 |
| IC | a. New Cost (NC) | 1182218 | 1067572 | 1178545 | 1030279 | 974720 |
| | b. NC as %age of Current Estimate | 100 | 90 | 100 | 87 | 82 |
| | c. NC as %age of New CI cost | 109 | 113 | 109 | 95 | 112 |
| | d. Rank of method | 2 | 2 | 2 | 2 | 2 |
| CI | a. New Cost (NC) | 1084773 | 947833 | 1079138 | 1084773 | 869372 |
| | b. NC as %age of Current Estimate | 100 | 87 | 100 | 100 | 80 |
| | c. NC as %age of New CI cost | 100 | 100 | 100 | 100 | 100 |
| | d. Rank of method | [1] | 1 | 1 | *3 | 1 |

KEY

[] - Denotes Current Estimate Ranking whose value has changed

* - Signifies change in ranking from Current Estimate

TABLE 7.16 The effect on cost of increasing the cost of Fuel, Skilled Labour, Unskilled Labour and Equipment Rental by 10%

| METHOD | PARTICULARS | CURRENT ESTIMATE | FUEL COST | SKLD LB COST | UNSKLD LB COST | EQUIP RENTAL |
|---|---|---|---|---|---|---|
| LI | a. New Cost (NC) | 1281835 | 1297649 | 1289653 | 1375260 | 1299938 |
| | b. NC as %age of Current Estimate | 100 | 101 | 101 | 107 | 101 |
| | c. NC as %age of New CI cost | 118 | 115 | 117 | 127 | 113 |
| | d. Rank of method | 3 | 3 | 3 | 3 | 3 |
| IL | a. New Cost (NC) | 1548667 | 1587857 | 1568041 | 1617788 | 1593530 |
| | b. NC as %age of Current Estimate | 100 | 103 | 101 | 104 | 103 |
| | c. NC as %age of New CI cost | 143 | 141 | 142 | 149 | 139 |
| | d. Rank of method | 4 | 4 | 4 | 4 | 4 |
| IC | a. New Cost (NC) | 1182218 | 1204674 | 1194462 | 1203229 | 1230848 |
| | b. NC as %age of Current Estimate | 100 | 102 | 101 | 102 | 104 |
| | c. NC as %age of New CI cost | 109 | 107 | 108 | 111 | 107 |
| | d. Rank of method | 2 | 2 | 2 | 2 | 2 |
| CI | a. New Cost (NC) | 1084773 | 1126272 | 1103554 | 1084773 | 1150048 |
| | b. NC as %age of Current Estimate | 100 | 104 | 102 | 100 | 106 |
| | c. NC as %age of New CI cost | 100 | 100 | 100 | 100 | 100 |
| | d. Rank of method | 1 | 1 | 1 | 1 | 1 |

TABLE 7.17 The effect on cost of increasing the cost of Fuel, Skilled Labour, Unskilled Labour and Equipment Rental by 33%

| METHOD | PARTICULARS | CURRENT ESTIMATE | FUEL COST | SKLD LB COST | UNSKLD LB COST | EQUIP RENTAL |
|---|---|---|---|---|---|---|
| LI | a. New Cost (NC) | 1281835 | 1334024 | 1284182 | 1590377 | 1341574 |
| | b. NC as %age of Current Estimate | 100 | 104 | 100 | 124 | 105 |
| | c. NC as %age of New CI cost | 118 | 109 | 118 | 147 | 103 |
| | d. Rank of method | [3] | 3 | 3 | 3 | *2 |
| IL | a. New Cost (NC) | 1548667 | 1678004 | 1554482 | 1776281 | 1696714 |
| | b. NC as %age of Current Estimate | 100 | 108 | 100 | 115 | 110 |
| | c. NC as %age of New CI cost | 143 | 137 | 143 | 164 | 130 |
| | d. Rank of method | 4 | 4 | 4 | 4 | 4 |
| IC | a. New Cost (NC) | 1182218 | 1256325 | 1185892 | 1241626 | 1342688 |
| | b. NC as %age of Current Estimate | 100 | 106 | 100 | 105 | 114 |
| | c. NC as %age of New CI cost | 109 | 103 | 109 | 114 | 103 |
| | d. Rank of method | 2 | 2 | 2 | 2 | 2 |
| CI | a. New Cost (NC) | 1084773 | 1221712 | 1090406 | 1084773 | 1300173 |
| | b. NC as %age of Current Estimate | 100 | 113 | 101 | 100 | 120 |
| | c. NC as %age of New CI cost | 100 | 100 | 100 | 100 | 100 |
| | d. Rank of method | 1 | 1 | 1 | 1 | 1 |

KEY

[] - Denotes Current Estimate Ranking whose value has changed

* - Signifies change in ranking from Current Estimate

TABLE 7.18 The effect on cost of increasing the cost of Fuel, Skilled Labour, Unskilled Labour and Equipment Rental by 50%

| METHOD | PARTICULARS | CURRENT ESTIMATE | FUEL COST | SKLD LB COST | UNSKLD LB COST | EQUIP RENTAL |
|---|---|---|---|---|---|---|
| LI | a. New Cost (NC) | 1281835 | 1360903 | 1285390 | 1749077 | 1372348 |
| | b. NC as %age of Current Estimate | 100 | 106 | 100 | 136 | 107 |
| | c. NC as %age of New CI cost | 118 | 105 | 118 | 161 | 97 |
| | d. Rank of method | [3] | 3 | 3 | 3 | *1 |
| IL | a. New Cost (NC) | 1548667 | 1744615 | 1557478 | 1893589 | 1772980 |
| | b. NC as %age of Current Estimate | 100 | 113 | 100 | 122 | 114 |
| | c. NC as %age of New CI cost | 143 | 135 | 142 | 175 | 126 |
| | d. Rank of method | 4 | 4 | 4 | 4 | 4 |
| IC | a. New Cost (NC) | 1182218 | 1294493 | 1187788 | 1270016 | 1425355 |
| | b. NC as %age of Current Estimate | 100 | 109 | 100 | 107 | 121 |
| | c. NC as %age of New CI cost | 109 | 100 | 109 | 117 | 101 |
| | d. Rank of method | [2] | 2 | 2 | 2 | *3 |
| CI | a. New Cost (NC) | 1084773 | 1292252 | 1093312 | 1084773 | 1411138 |
| | b. NC as %age of Current Estimate | 100 | 119 | 101 | 100 | 130 |
| | c. NC as %age of New CI cost | 100 | 100 | 100 | 100 | 100 |
| | d. Rank of method | [1] | 1 | 1 | 1 | *2 |

KEY

[] - Denotes Current Estimate Ranking whose value has changed

* - Signifies change in ranking from Current Estimate

7.6.4 Sensitivity Analysis Results Presentation and Discussion

The results from the sensitivity analysis are summarised in Tables 7.15 to 7.18. The ranking of the methods shown in these tables is based on cost. The current estimate is the result from analysis carried out at the current market rates (and is obtained from Table 7.3). This current estimate is taken as the standard data with which the new costs are compared.

The effects of varying each of the four factors mentioned above on each method of construction are discussed. The response of each method to the variations in these factors is also discussed. A general observation for each cost variation is also given.

7.6.4.1 The effect of decreasing the costs by 33% (-33%) of the Market Rates (see Table 7.15)

(A) How a decrease in the Market Rates of individual factors by 33% affects the various methods of construction

(a) Fuel Cost

A 33% decrease in fuel cost does not seem to alter the order of preference of methods. However, one noticeable feature is that the differences in costs between the other methods and the CI cost are slightly higher than the current estimate. The CI method is the most affected by decrease in fuel cost while the least affected method is the LI method.

(b) Skilled Labour Cost

A decrease in skilled labour cost by 33% does not change the order of preference and there is very insignificant effect on the current estimates.

(c) Unskilled Labour Cost

Decreasing unskilled labour cost by 33% seems to have a noticeable change in the ranking of the methods with the LI method being the most preferred and the IL method least preferred. The CI method costs are not affected by this decrease in unskilled labour cost. The decrease results to a 24% decrease in LI cost from the current estimate.

(d) Equipment Rental

As in (a) above, the ranking is not affected by a 33% decrease in equipment rental. This decrease also results to a slightly higher difference in cost between the CI method and the other methods when compared to the current estimates. The results also show that the equipment oriented methods (IC and CI) are the ones most affected by a decrease in equipment rental.

(B) How the various construction methods respond to a decrease in market Rates of the various factors by 33%

(a) Labour Intensive (IL) method

The LI method is not affected by a 33% decrease in skilled labour cost but is most affected by the decrease in unskilled labour cost which results to a 24% decrease in current costs. The decreases in fuel cost and equipment rental have about the same effect on the LI method resulting to a 5% to 6% reduction on current LI cost.

(b) Intermediate L (IL) method

This method is almost unaffected by the decrease in skilled labour cost. The fuel cost and equipment rental decrease seem to have about the same effect on the IL cost. The method is however most sensitive to the decrease in unskilled labour cost which results to a 15% reduction on current IL cost.

(c) Intermediate C (IC) method

This method seems to be significantly sensitive to a 33% decrease in all factors except skilled labour. However, the decrease in equipment rental has the greatest effect resulting to an 18% reduction on current costs.

(d) Capital Intensive (CI) method

The CI method seems almost unresponsive to a 33% decrease in skilled labour and unskilled labour costs. The method is however most sensitive to a 33% decrease in equipment rental resulting to a 20% reduction in cost from current estimate.

(C) General Remark on the decrease in Market Rates by 33%

A decrease of 33% in costs of the various factors of costs considered has varying effects on the various methods of construction. There are however some outstanding observations. These are summarised as;

(i) Decreasing Skilled Labour cost by 33% has very insignificant effect on all methods.

(ii) The equipment oriented methods (IC and CI) are affected most by a decrease in equipment rentals and also significantly by a decrease in fuel cost.

(iii) Unskilled labour cost decrease by 33% has a noticeable effect on all the methods except the CI method. It is also noticeable that this factor cost variation results to a change in the ranking of the methods.

7.6.4.2 The effect of increasing the costs by 10% of the Market Rates (see Table 7.16)

(A) How an increase in the Market Rates of individual factors by 10% affects the various methods of construction

(a) Fuel cost

The 10% increase in fuel cost does not have any effect on ranking of method. There is also a small reduction in the range between the CI cost and other costs. The most affected method is the CI method with a 4% increase in cost over current cost. The least affected method is the LI method.

(b) Skilled Labour Cost

Increasing the skilled labour cost by 10% has very small effect on costs for all the methods. The ranking of the methods remains the same as in the current estimate.

(c) Unskilled Labour Cost

An increase of 10% on unskilled labour cost has no effect on the ranking of the methods. The most affected method is the LI method with an increase on current cost of 7%. The CI method is least affected by this increase in cost.

(d) Equipment Rental Rate

The method most affected by a 10% increase in equipment rental rate is the CI method resulting to an increase on current cost of 6%. The LI method is the least affected. The IL and IC methods are affected in almost the same ratio. Another notable feature is that the range between the CI method costs and the costs of the other methods is lower than in the current estimate.

(B) How the various construction methods respond to an increase in market rates of the various factors by 10%

(a) Labour Intensive (LI) Method

Compared to the other factors, a 10% increase in unskilled labour cost seems to have the largest effect (increasing the LI current cost by 7%). Similar increases of fuel cost, equipment rental and skilled labour have just about the same effect on the LI method (increasing the current LI cost by only 1%).

(b) Intermediate L (IL) Method

This method is affected most by a 10% increase in unskilled labour. Skilled labour increase by the same percentage has the least effect while equipment rental and fuel cost similar increases have just about the same effect on the LI cost.

(c) Intermediate C (IC) Method

The IC method is affected most by a 10% increase in equipment rental and least by a similar increase in skilled labour cost. Fuel cost and unskilled labour cost increase by 10% have just about the same effect on the IC cost.

(d) Capital Intensive (CI) Method

A 10% increase in equipment rental seems to have the largest effect on the CI method (increasing current CI cost by 6%). A similar increase in cost of unskilled labour has no effect on the CI cost. Increasing the fuel cost by the same fraction results to an increase of 4% on the current estimate while a similar increase in skilled labour increases the CI current cost by half the amount (2%).

(C) General Remark on the increase in Market Rates by 10%

As is expected, each of the four factors affect the various methods differently. However a few observations can be made;

(i) Increasing skilled labour cost by 10% seems to have very little effect on all the methods.

(ii) The machine oriented methods (IC and CI) are affected most by a 10% increase in equipment rental rate.

(iii) A 10% increase in the cost of the factor inputs considered has no effect on the ranking of the methods.

### 7.6.4.3. The effect of increasing the costs by 33% of the Market Rates (see Table 7.17)

#### (A) How an increase in the Market Rates of Individual factors by 33% affects the various methods of construction

(a) Fuel Cost

Fuel cost increase by 33% does not affect the ranking of the methods. The most affected method is the CI method (resulting to an increase of 13% on current CI cost) while the least affected is the LI method with an increase of only 4% on current LI cost. The difference in cost between the CI cost and all the other methods is less than in the current estimate.

(b) Skilled Labour Cost

Increasing skilled labour cost by 33% does not seem to have any significant effect on the costs of all the methods. The ranking of the methods is also not affected.

(c) Unskilled Labour Cost

An increase of 33% on the cost of unskilled labour results to an increase in the difference between the CI cost and all the other methods. The most affected method is the LI method with an increase of 24% over the current estimate. The CI method is not affected at all.

(d) Equipment Rental Rate

A 33% increase in equipment rental rates results to change in ranking of the methods. The most preferred method remains the CI method followed closely by the LI and IC methods which have the same ranking and only 3% higher in cost over the CI method. It is also noticed that the CI method responds most to this increase in cost resulting to a 20% increase on current CI cost. The least affected method is the LI method with only a 5% increase over current LI cost.

#### (B) How the various construction methods respond to an increase in Market Rates of the various factors by 33%

(a) Labour Intensive (LI) method

This method is most affected by the 33% increase in unskilled labour cost (resulting to 24% increase in cost over current estimate) and almost unaffected by a similar increase in skilled labour cost. Increasing the cost of fuel and equipment rental rate has just about the same effect on the LI method.

(b) Intermediate L (IL) Method

The IL method remains unaffected by a 33% increase in skilled labour cost. However, a similar increase in unskilled labour cost has the largest effect which increases the current estimate by 15%. Similar increases in the costs of fuel and equipment rental have almost similar effects on the IL cost increasing the current estimate by 8 to 10%.

(c) Intermediate C (IC) Method

A 33% increase in equipment rental seems to have the largest effect on this method resulting to an increase of 14% on the current IC estimate. Skilled labour cost increase is the most insignificant variation. Similar increases of fuel and unskilled labour cost have about the same effect on this method.

(d) Capital Intensive (CI) Method

The CI method is most affected by an increase in equipment rental rate (20% higher than current estimate) and only affected insignificantly by a similar increase in skilled labour cost. The method is not affected at all by unskilled labour cost variation. Increasing the fuel cost by 33% has just over half the effect of an equal increase in equipment rental rate.

(C) General Remark on the increase in Market Rates by 33%

The various methods of construction are affected differently by a 33% increase in the cost of the various factors. There are however some few notable features;

(i) An increase of 33% on skilled labour cost has insignificant effect on all methods

(ii) Increasing the cost of fuel and equipment rental by 33% affects IC and CI methods mostly

(iii) An increase of 33% on equipment rental results to a change in ranking of methods.

7.6.4.4 The effect of increasing the costs by 50% of the Market Rates (see Table 7.18)

(A) How an increase in the Market Rates of individual factors by 50% affects the various methods of construction

(a) Fuel cost

A 50% increase in fuel cost does not seem to affect the ranking of the methods. One noticeable feature is that the CI and IC methods cost about the same and the LI method method costs only 5% higher than the CI costs. The fuel cost increase has the greatest effect on the CI method resulting to an increase of 19% on the current costs. The least affected method is the LI method costing only 6% higher than the current.

(b) Skilled Labour Cost

Increase in skilled labour cost has no effect on the ranking of the methods and has very insignificant effect on the costs of all the methods.

(c) Unskilled Labour Cost

As in the fuel and skilled labour cases, an 50% increase in unskilled labour cost has no effect on the ranking of the methods. The LI method is the most responsive on the increase in unskilled labour rate resulting to an increase of 36% on current LI estimate. The CI method is not affected at all by this factor.

(d) Equipment Rental Rate

Increasing the equipment rental rates by 50% results to a change in the order of ranking of the methods with the LI method being first preference followed by the CI method. The IC method comes third though it would be considered to be ranked the same as the CI method since it costs only 1% higher than the CI method. The CI method is affected most resulting to an increase of 30% over current estimate. The method affected least by this increase is the LI method costing only 7% higher than the current estimate.

(B) How the various construction methods respond to an increase in the Market Rates of the various factors by 50%

(a) Labour Intensive (LI) Method

This method in not affected greatly by a 50% increase in skilled labour while similar increases in fuel costs and equipment rental rates have about the same effect (of increasing current LI cost by 6 to 7%). Increase in unskilled labour cost by 50% has the greatest effect resulting to a 36% increase on the current costs.

(b) Intermediate L (IL) Method

The IL method is most sensitive to the 50% increase in unskilled labour cost resulting to a 22% increase on current cost. Fuel cost and equipment rental rates increases seem to have about the same effect on the IL method while the increase in skilled labour cost seems to have no noticeable effect on cost.

(c) Intermediate C (IC) Method

The IC method seems to be affected most by a 50% increase in equipment rental rates which results to costs 21% higher than the current estimate. Increasing the skilled labour cost does not seem to affect the method significantly. A 50% increase in fuel costs results to about 9% increase in the current IC cost which is almost half the increase in cost resulting from a similar increase in equipment rental. Unskilled labour cost increase by 50% also has a noticeable effect on the cost (7% increase on current IC cost).

(d) Capital Intensive (CI) Method

The CI method is almost insensitive to increases in skilled labour and unskilled labour. The method is however most sensitive to increase of 50% on the equipment rental which results to an increase of 30% on the current CI cost. A similar increase in the fuel cost results to a 19% increase in the current estimate of CI method.

(C) General Remark on the increase in Market Rates by 50%

Increasing the costs of the four factors has varying effects on the costs of the various methods. Some notable features are;

(i) Increase in the cost of skilled labour has no or very insignificant effect on the costs of the methods or on the ranking

(ii) A 50% increase in fuel cost and equipment rental rates affects mostly the IC and CI methods

(iii) An increase of 50% on equipment rental rate seems to have the largest effect since it results to a change in ranking of the methods

### 7.6.5 <u>General Remarks on the Sensitivity Analysis</u>

A sensitivity analysis has been carried out to show the effect of varying the costs of various factors of input.

The results show that even by increasing the costs of the selected factors by up to 10%, it is still possible to predict with confidence the best method of construction for a particular set of conditions.

From the analysis it was also found that it was only by reducing or increasing the costs by 33% that the ranking of the methods was found to change. This therefore implies that the errors and/or variations would have to be great (in the order of + or - 33%) for the ranking of the methods to be affected.

The effect on cost of increasing or decreasing the productivity of the various factors of input (labour and equipment) is inversely proportional to corresponding equal changes in the equipment rental rates therefore the effects of changes to productivities will be the reverse of those for costs.

The sensitivity analysis has also been shown to help identify the factors that are most critical to the costs of the various methods e.g. variations in the cost of skilled labour were found to be of insignificant effect on the methods while equipment rental rates, fuel cost and unskilled labour cost variations have their own individual effects on the methods depending on the magnitude of variation. Hence the need for thorough investigation on these factors before any decision can be made on method of construction.

# CHAPTER 8

# A PROCEDURE FOR APPLYING THE METHOD OF EVALUATION

## 8.1 GENERAL

In this chapter is given a summary of how to apply the techniques developed in this study to investigate the costs and durations of alternative methods of construction.

The type of data required is presented and the possible sources are suggested. The procedure is summarised in Steps 1 to 9 given below.

## 8.2 THE PROCEDURE

<u>Step 1</u>: <u>Work Establishment</u>
Identify all the works to be carried out for the particular project being investigated. It is important at this stage to identify all the activities that comprise various tasks.

As an example let the major tasks for a project be:

Task A: Excavate over site and haul

Task B: Excavate foundation trenches and haul

Both Tasks A and B are comprised of the activities of EXCAVATE and HAUL.

Obtain all the details of the activities e.g. description and quantity and enter all these details in a database. A typical database is presented in Step 8 below as Table 8.1.

<u>Step 2</u>: <u>Analyse Tasks</u>
Identify tasks that can be executed by more than one way. It is important that the particular characteristics of each task be identified (e.g. in an earthworks hauling activity, haul distance may be critical while in an excavation activity, soil type may be an important consideration).

<u>Step 3</u>: <u>Establish Sequence of Activities</u>
Establish the sequence of operation (e.g. using a network diagram) to

help determine interdependence of activities. For the example being considered, it can be assumed that the sequence is as shown below for both Tasks A and B,

Start ⟶ Excavate ⟶ Haul ⟶ End

Step 4: Resource Establishment

Establish the type of resources (e.g. equipment and labour) options that can be used and are available for the various tasks identified in Step 1 above. The resources are grouped according to their functions. It can be assumed that the options available to carry out the activities of EXCAVATION and HAULING are (see Chapter 5);

Excavating Equipment: E1 - Bulldozer Option 1 (excavating and hauling)
E2 - Bulldozer Option 2 (excavating and Loading onto hauling equipment)
E3 - Hand Tools (excavation and loading)

Hauling Equipment : H1 - Bulldozer Option 1 (same as E1)
H2 - Tipper Truck
H3 - Tractor Trailer Option 1 (loaded mechanically and unloaded with hand tools)
H4 - Wheelbarrow

Information on the possible alternative options available for the various tasks can be obtained from contractors, evaluators' experience and observations or one may wish to try out new methods.

Step 5: Establish Resource Productivity Details

To establish the productivities of the various resources identified in Step 4 above is the most involved part of the data collection exercise. Nevertheless productivity data for heavy equipment can be obtained from the manufacturers' handbooks (which at times may require adjusting to suit local conditions as was done in this work by reducing the manufactures productivities by 60% to suit Kenyan conditions).

Another source of productivity data is from works done by such organisations as the World Bank and the International Labour Organisation (ILO). These organisations have done substantial investigations especially on Labour/Capital substitution in civil engineering works in developing countries.

Contractors and evaluators' own experience is also another source of productivity data.

(In Chapter 5 the productivity estimates for this study for the various resources considered are presented.)

Step 6: Establish Resource Unit Rates

The establishment of the unit rates for the various resources identified in Step 4 is another very important aspect of the analysis. The basic wage rates for the labour inputs may be obtained from the relevant government departments or other reliable sources while the equipment rental rates can be obtained from contractors or other firms that rent or lease out equipment and plant.

It is important that all costs are taken into account as outlined in Chapter 4.

Step 7: Establish Compatibility

For interdependent activities, compatibility (or balancing) of equipment and labour resources is checked and maintained to ensure realistic combinations of resources e.g. In the earthworks task of excavation and subsequent hauling, a wheelbarrow cannot be used for hauling when excavation and loading is being done by a Cat D6 bulldozer or hauling by a tipper truck when the excavation and loading is done by use of hand tools.

It is important at this stage to investigate all viable and realistic compatibilities of the various resources. As in previous steps, ideas on viable options can be obtained from works done on similar jobs elsewhere, enquiring from different contractors and engineers and from the evaluators' experience and creativity.

Step 8: Database Establishment

Compile all the data from Step 1 to 7 above into appropriate databases (as shown below). The fields of the databases should include all the relevant information for the particular options under consideration. In

Tables 8.1 to 8.3 shown below is the kind of information considered necessary for almost any input factor (option) for most projects. As an example, the options for Tasks A and B are used.

Table 8.1 Task Details (TASKS database file)

| Record | Activity | Quantity | Comp_with |
|---|---|---|---|
| 1 | Task A | ***** | E1, E2, E3 |
| 2 | Task B | ***** | E2, E3 |

Where "Comp_with" column contains the abbreviation of the equipment or other resource used to carry out the first activity in the task.

Table 8.2 Details of Excavating Equipment (say EXCAVATE database file)

| Record | Short | Descript | Prod | Unit(P) | U_Rate | U_Avlb | Comp_with |
|---|---|---|---|---|---|---|---|
| 1 | E1 | **** | ** | *** | *** | *** | H1, |
| 2 | E2 | **** | ** | *** | *** | *** | H2, H3 |
| 3 | E3 | **** | ** | *** | *** | *** | H4 |

Table 8.3 Details of Hauling Equipment (say HAUL database file)

| Record | Short | Descript | Prod | Unit(P) | U_Rate | U_Avlb |
|---|---|---|---|---|---|---|
| 1 | H1 | **** | ** | *** | *** | ** |
| 2 | H2 | **** | ** | *** | *** | ** |
| 3 | H3 | **** | ** | *** | *** | ** |
| 4 | H4 | **** | ** | *** | *** | ** |

where for Tables 8.2 and 8.3;

Short : An abbreviation of the type of equipment
Descript : A brief description of the equipment type
Prod : The productivity of the particular resource
Unit(P) : The units of productivity (e.g. in units of work done per resource hour)
U-Rate : Shows the unit rate as established in Step 6
U-Avlb : The number of units of the particular resource available

Comp_with: Where applicable, shows the abbreviation of the equipment(s) for the next activity which is/are compatible with the particular equipment under investigation

Any other desirable details can be incorporated in these tables to suit specific needs.

Step 9: How to Analyse the Data

In Chapter 6 the detailed method of analysing the data is given. In brief the costs and durations are calculated as shown below.

Duration

For a particular task the duration is arrived at from the individual durations required to carry out individual activities that constitute the task under consideration. For example the time taken to carry out Task A is the maximum of time to excavate and the time to haul since these activities are interdependent. Thus the final task duration is dependent on the slowest operation.

Each of the durations is calculated as shown below;

$$\text{Time} = \frac{\text{Quantity of Work (as shown in the TASKS dbf)}}{\underset{\text{(of particular Eqpt)}}{\text{Productivity}} \times \text{Units Available (U\_Avlb)}}$$

Cost

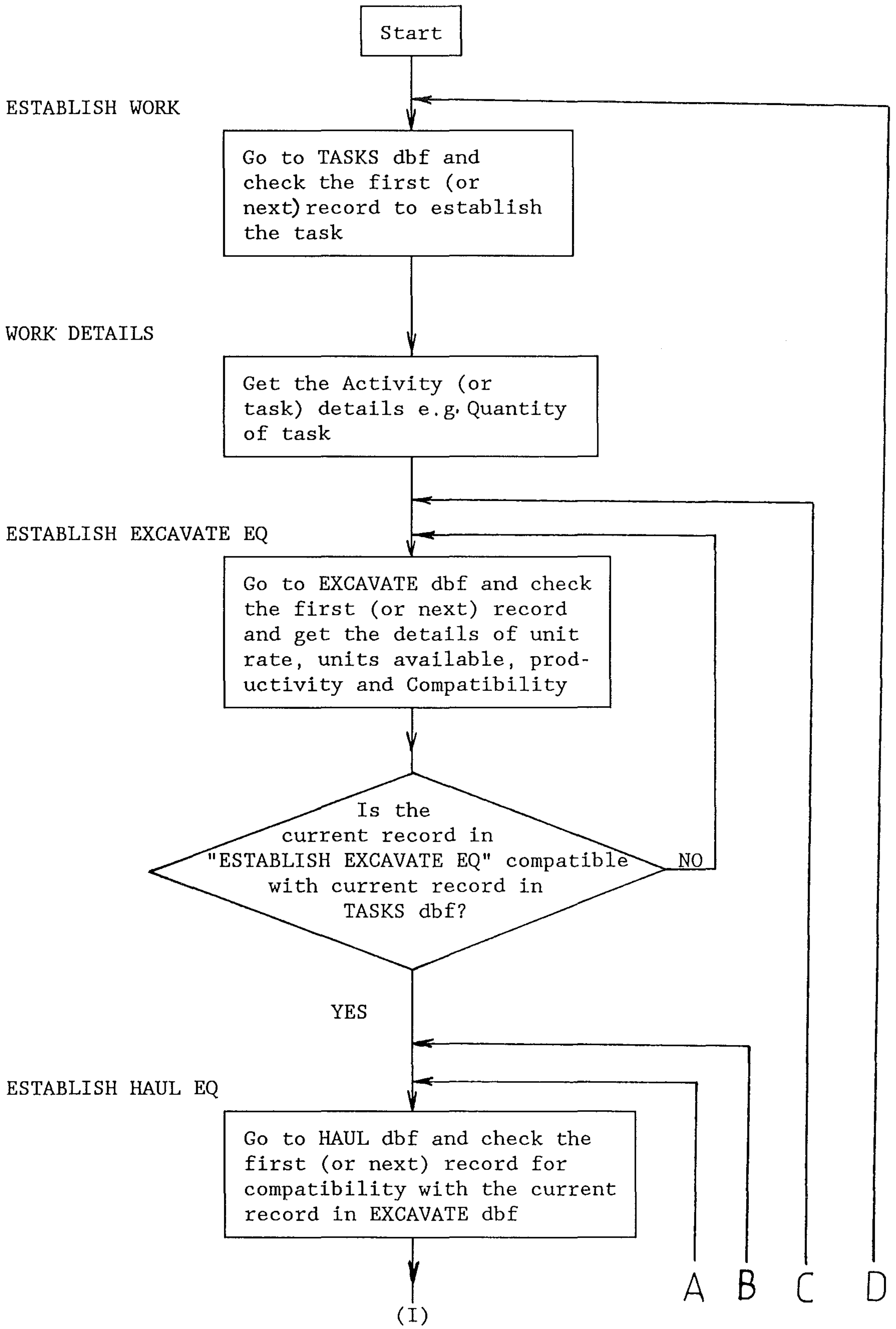
The total cost of carrying out a task is considered to be the sum of the costs of carrying out the individual activities that comprise that task. For example the cost of carrying out Task A is taken as the sum of the cost of Excavating and Hauling. The cost of each activity is based on the unit rates as they are given in the individual databases. Because of interdependence of these activities, the cost of each is considered to depend on the slowest activity as established above.

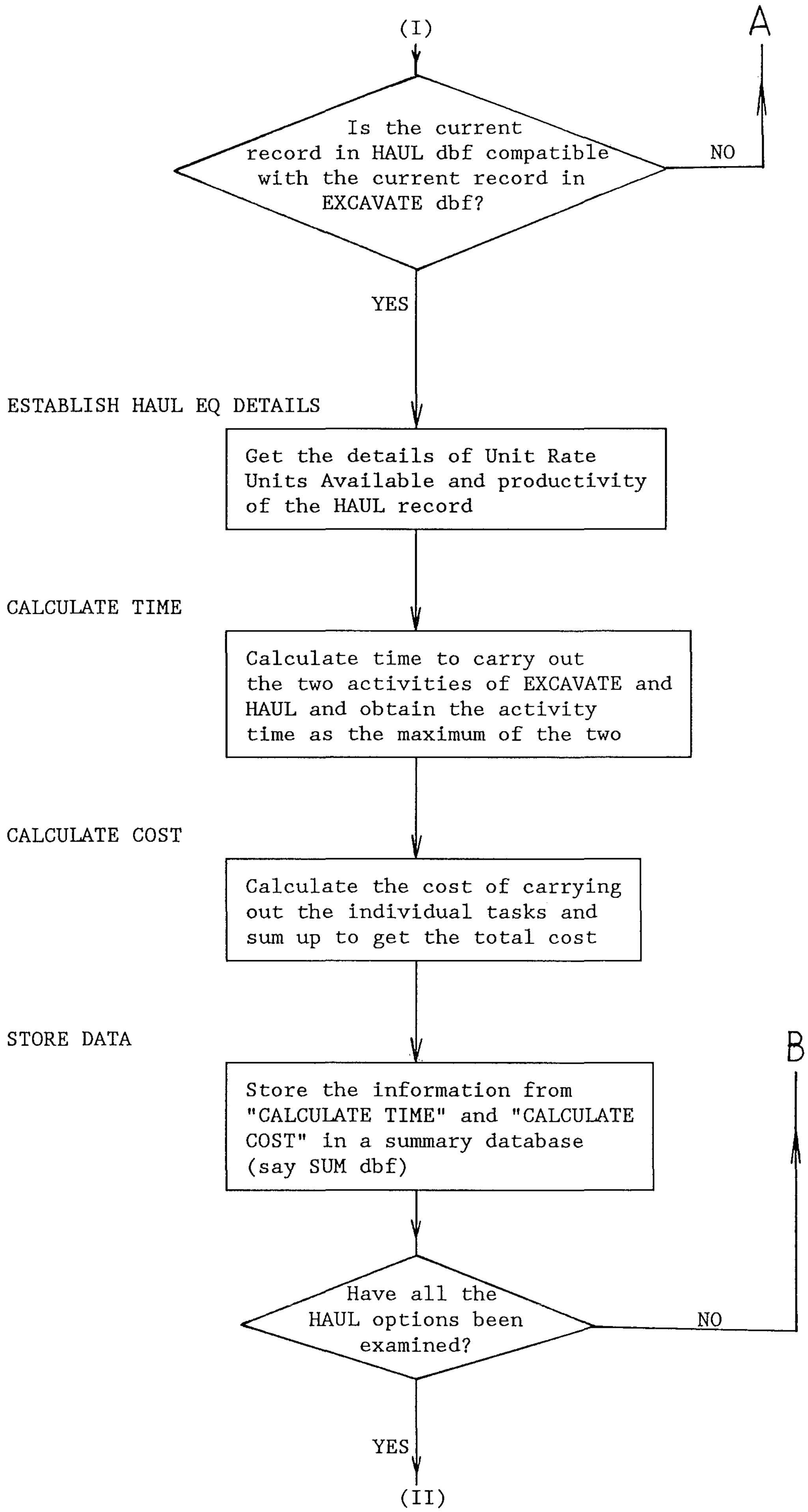
The general formula for each activity is;

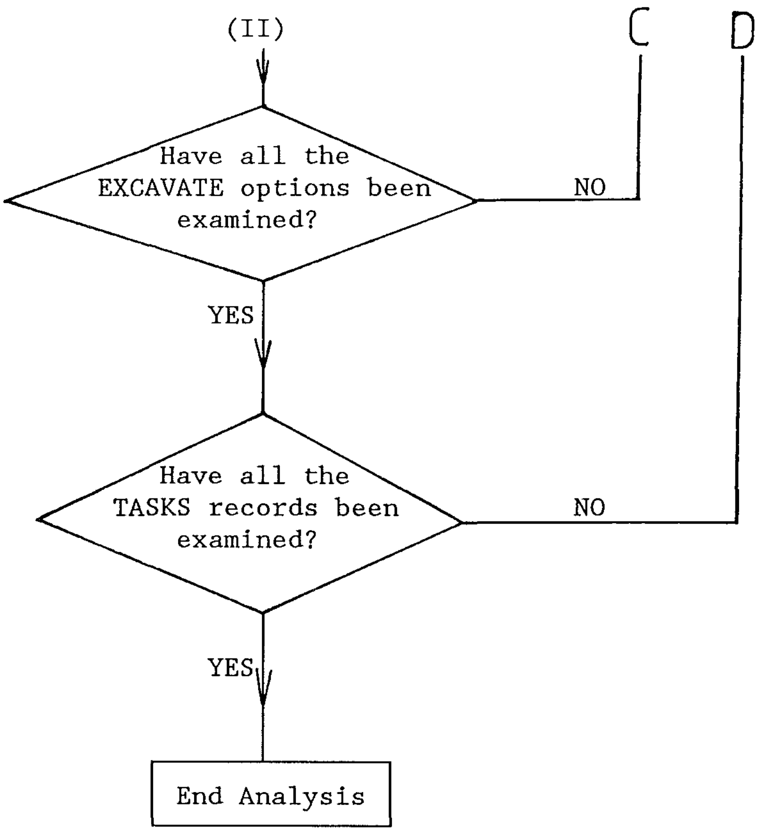
Activity cost = Unit Rate x Activity Time x Units available

A flow chart describing the process of evaluating the data shown in Tables 8.1 to 8.3 is given below.

Figure 8.1 Flow Chart for the Current Example




(I)
A
Is the current record in HAUL dbf compatible with the current record in EXCAVATE dbf?
NO
YES
ESTABLISH HAUL EQ DETAILS
Get the details of Unit Rate Units Available and productivity of the HAUL record
CALCULATE TIME
Calculate time to carry out the two activities of EXCAVATE and HAUL and obtain the activity time as the maximum of the two
CALCULATE COST
Calculate the cost of carrying out the individual tasks and sum up to get the total cost
STORE DATA
B
Store the information from "CALCULATE TIME" and "CALCULATE COST" in a summary database (say SUM dbf)
Have all the HAUL options been examined?
NO
YES
(II)




## 8.3 FORM OF RESULTS

Durations and costs for the various possible combinations of equipment and labour are entered into a summary database automatically as they are calculated. If for the current example the summary database is SUM dbf, then possible fields of this database would be;

JOBPART : Description of the task under consideration
EXCEQ : Abbreviation of equipment used to excavate
EXCTIME : Actual time to excavate
HAULEQ : Abbreviation of equipment used to haul
HAULTIME : Actual time to haul
JOBTIME : Minimum time required to complete each task
JOBCOST : Minimum cost of the task under consideration for a particular equipment combination
CLASS : Shows the category of method as either Labour Intensive, Capital Intensive or any other suitable combination of the two extremes

The choice of contents of the fields in the summary database, as in compiling of the databases, is at the discretion of the evaluator who knows what details are required most for the analysis.

The summary database, SUM dbf, with fields as shown above would be as shown in Table 8.4 below.

TABLE 8.4 Durations and Costs for the viable methods of construction for the Example Project (SUM dbf)

| JOBPART | EXCEQ | EXCTIME | HAULEQ | HAULTIME | JOBTIME | JOBCOST | CLASS |
|---|---|---|---|---|---|---|---|
| TASK A | E1 | ** | H1 | ** | ** | ** | ** |
| TASK A | E2 | ** | H2 | ** | ** | ** | ** |
| TASK A | E2 | ** | H3 | ** | ** | ** | ** |
| TASK A | E3 | ** | H4 | ** | ** | ** | ** |
| TASK B | E2 | ** | H2 | ** | ** | ** | ** |
| TASK B | E2 | ** | H3 | ** | ** | ** | ** |
| TASK B | E3 | ** | H4 | ** | ** | ** | ** |

From the summary database one can proceed with selection of the most suitable method of construction depending on the criteria for selection of "best".

The effect on cost and/or duration of varying any one of the variables like unit-rate, productivity and availability of units can be evaluated as outlined in Chapter 7 section 7.6 on Sensitivity Analysis.

## 8.4 SUMMARY

A simplified method of how to apply the techniques developed in this study has been presented with the type of data required and possible sources of the data suggested.

The actual programs follow the same general principles as those listed in Appendix C with only slight modifications for specific needs.

Applying this procedure will be of great assistance in evaluation of alternative methods of construction.

# CHAPTER 9

# CONCLUSIONS, IMPLICATIONS AND RECOMMENDATIONS FOR FURTHER RESEARCH

## 9.1 GENERAL

This chapter includes the major conclusions that are arrived at from this study. The implications of the findings and recommendations for further research are also presented.

## 9.2 CONCLUSIONS

The problems and restrictions of the construction industry in developing countries have been identified. As a way of providing a possible solution to some of these problems, a method of analysing costs and durations of alternative methods of construction has been developed. The use of the method has been illustrated by its application to three projects: a gravel road project, a three storeyed building project and an oxidation ponds project.

From the analysis of durations and costs for the three projects carried out, it is evident that every particular project has its own characteristics as regards best method of construction. This work has also shown how a wide range of results can be obtained to help project evaluators decide on the best method of carrying out particular works.

While most of the analysis and discussion has been based on a project level with emphasis on the major tasks of earthworks and concreteworks, the same approach can be used to analyse individual projects at the task level. Such an analysis would highlight to the evaluators the benefits of using one method and not the other.

It has been shown in Chapter 7 that costs at market rates may give a totally different impression from those at shadow rates hence the need to determine an appropriate shadow rate using local advice and knowledge when evaluating costs of alternative methods. The low equipment utilisation rates in most developing countries and the limited facilities for maintenance in addition to restraints on foreign exchange (with which to import essential parts) are some of the factors that may justify assumption of high shadow rental rates for equipment. The abundance of unemployed unskilled labour on the other hand justifies assumptions of low shadow wage rates for unskilled labour and all this works to emphasize the need to evaluate projects at the appropriate rates (market or shadow) before any decision is made on method of construction.

One major feature of the construction industry is the urgency which clients almost always attach to the design and construction of their projects. As a result of this, engineers have little time to consider other options and the contractors complain of the short time they are given to price the jobs. This urgency severely constrains the number of construction options that could otherwise be considered for a given project and often leads to adoption of methods that may even be inappropriate.

The method developed and used in this work can be used to evaluate costs and times of alternative methods with readily available data for different jobs and in other countries (as outlined in Chapters 6 and 8). All that is required is the identification of the resources available, estimate of their productivities and unit rates and then the analysis as outlined in Chapters 6 and 8. With the speed and accuracy that the method provides, the costs and durations of alternative methods can be estimated. The effects of variations in the factor inputs like costs, wages and availability of equipment can also be examined quickly.

To show how these variations can be examined, a method of carrying out sensitivity analysis has been presented for one of the projects. This helps to give the engineer the limit of confidence on which to base selection of method of construction. The sensitivity analysis also gives some helpful information as to which factors of input are most critical on the costs of the various methods.

The method therefore enables quick assessment of the relative merits of alternative construction methods thus giving a good chance for consideration and adoption of more appropriate methods of construction.

## 9.3 IMPLICATIONS OF THE STUDY AND FINDINGS

The development of a convenient method of evaluating costs and durations of alternative methods of construction has a wide implication on a large cross section of important groups of people. The implications on various groups are summarised below.

### 9.3.1 Engineers and Decision Makers

Engineers in developing countries need to make concerted efforts to focus the attention of their governments on the need for sound policies on technologies. This is especially important in view of the fact that most of the major construction works are government projects which usually have great potential for use of more appropriate methods.

The tendency of awarding contracts to only those contractors who own capital assets can be interpreted as a way of recommending (if not dictating) what methods of construction must be used on particular works. This tendency needs to be reviewed if alternative and more appropriate methods of construction are going to be taken seriously.

### 9.3.2 Training Institutions

Universities and polytechnics need to be given sufficient funding to enable them develop appropriate technologies for the local construction industry. Such funding could be obtained from local cement, steel, brick or other industries producing or marketing construction materials as well as from the government.

Training centres and workshops offering post-experience courses in design and construction need to be set up. This will allow those (engineers and contractors) experienced in alternative methods to pass on their experience to upcoming younger engineers and other key personnel. This would add incentive to all those concerned in addition to creating a pool of useful technical information for future reference.

### 9.3.3 Donor Agencies

Aid given to developing countries should allow flexibility (with accountability) on its use especially where it involves design and construction. The donors should insist on using locally available resources whenever possible.

### 9.3.4 <u>Others</u>

This group includes local artisans who manufacture small tools and simple equipment that are used in construction. Their expertise and innovativeness need to be more appreciated and utilised by engineers and others especially in the effort of devising or modifying alternative methods of construction.

## 9.4 RECOMMENDATIONS FOR FURTHER RESEARCH

(a) There is need for compiling a databank of productivity rates for particular regions. This would probably involve using existing information and establishing what variations exist between productivity values in various countries.

(b) More work needs to be done in the costing of the non-quantifiable aspects of construction.

(c) There is need to investigate application of the method developed on more complex projects with more complex tasks.

(d) The method developed needs to be applied to data from other countries.

## 9.5 CONCLUDING REMARKS

A method of investigating the costs and durations of alternative methods of construction has been developed and tested along with sensitivity analysis. The method is directly applicable to selection of construction method wherever a choice of construction methods is available. The use of the method will be of great assistance in evaluation of alternative methods of construction.

# REFERENCES

1. BEENHAKKER H.L. with CARAPETIS S., CROWTHER L. and HERTEL S., Rural Transport Services; A Guide to their Planning and Implementation. Intermediate Technology Publications, 1987. 379p

2. CAPT. J. and EDMONDS G.A., Study of Small Contractors in Kenya; World Employment Programme Research Working Paper No.33, International Labour Office, Geneva, 1977. 26p

3. COLLIER K., Fundamentals of Construction Estimating and Cost Accounting; New Jersey, Prentice Hall, Inc., 1974. 296p

4. COSTA' E., GUHA S., HUSSAIN M.I., THUY N.I.B., and FARDET A., Guidelines for the Organisation of Special Labour Intensive Works Programmes; A World Employment Programme, International Labour Office, Geneva, 1979.

5. de VEEN J.J., The Rural Access Roads Programme; Appropriate Technology in Kenya. International Labour Office, Geneva, 1980. 167p

6. ENTERKIN H. and REYNOLDS G., Estimating for Builders and Surveyors 2nd ed. London, Heinemann, 1978. 408p

7. HARRIS F., Construction Plant; Excavating and Materials Handling, Equipment and Methods. Granada, London, 1981. 230p

8. INTERNATIONAL LABOUR OFFICE, Report to the Government of Pakistan on the use of Labour Intensive Methods for The Indus Super Highway, 1977. 93p

9. INTERMEDIATE TECHNOLOGY DEVELOPMENT GROUP, Kenyan Building Contractors; Practices, Problems and Needs; Information Paper No.8, 1973.

10. KARAA F.A. and NASR A.Y., Resource Management in Construction, Journal of Construction Engineering and Management (ASCE), Vol. 112, No.3, 1986.

11. KRISHNAN V., Appropriate Technology for Fiji. Master of Engineering Report, University of Canterbury, New Zealand, 1983.

12. LAL D. assisted by HEAP A., BOISEN H., NILSSON B. and KARLSON L., Men or Machines; A Study of Labour - Capital Substitution in Road Construction in the Philippines, International Labour Office, Geneva, 1978. 164p

13. LITTLE I.M.D. and MIRRLEES J.A., Project Appraisal and Planning for Developing Countries, Heinemann, London, 1974.

14. McCLEARLY W.A. in collaboration with ALLAL M. and NILSSON B., Equipment Versus Employment; A World Employment Programme Study, International Labour Office, Geneva, 1976. 160p

15. MUNIR M., Substitution of Labour Intensive Methods in Projects; A Master of Engineering Thesis Report, Asian Institute of Technology, Bangkok, Thailand, 1978.

16. PERERA S., Resource Sharing in Construction; Journal of Construction Engineering and Management (ASCE), Vol.109, No.1, 1983. pp 102 - 111

17. SCOTT D., Choosing the Appropriate Method of Construction; International Journal for Development Technology, Vol.4, 1986. pp 205 - 213

18. SCOTT M.F.G., McARTHUR J.D., NEWBERY D.M.G., Project Appraisal in Practice; The Little - Mirrlees Method Applied in Kenya, 1976.

19. SCOTT WILSON KIRKPATRICK and partners (WORLD BANK), Appropriate and Labour Based Construction, 1974 - 1977.

20. SHEIKH N.A., Optimal Allocation of Scarce Resources in the Construction Industry; A Master of Engineering Thesis, Asian Institute of Technology, Bangkok, Thailand, 1977.

21. SRIDURONGKATUM S., A Study of Construction Methods of Low Income Multifamily Houses; A Master of Engineering Thesis, Asian Institute of Technology, Bangkok, Thailand, 1978.

22. WILSON F., Design Calculations in Waste Water Treatment, 1981

23. Anon, Technical Memoranda (WORLD BANK), Nos. 3 and 13, 1975.

# BIBLIOGRAPHY

1. ALLAL M. and EDMONDS G.A. in collaboration with BHALLA A.S., Manual on the construction of Labour Intensive Roads. International Labour Office, Geneva, 1977.

2. Appropriate Technology in Civil Engineering; Proceedings of the Conference held by the Institution of Civil Engineers, London, 14 - 16 April 1980.

3. dBXL - The New dBASE III PLUS Compatible Database Management System WordTech Systems.

4. DAY D.A., Construction Equipment Guide, 1973.

5. EDMONDS G.A. and HOWE J.D.F.G., Roads and Resources; Appropriate Road Construction in Developing Countries. Intermediate Technology Publications for the ILO, 1980.

6. GROUT G., Business Computing for Small Contractors, 1986.

7. NUNNALLY S.W., Managing Construction Equipment, 1977.

8. PAGE J.S., Estimators General Man-hour Manual, 2nd edition, 1983.

9. SINGER H., Technologies for Basic Needs; A WEP Study, International Labour Office, Geneva, 1982.

10. STEWART F., Choice of Technology in Developing Countries; Journal of Development Studies Vol.9, 1972-1973.

11. UKO C.E.A., Aquisation of Construction Technology by Less Developed Countries; International Journal for Development Technology, Vol.4, 1986.

12. Anon, Technical Memoranda (WORLD BANK), Nos 7,8,17,18,19 and 20, 1975-76.

# APPENDIX A

# HAULING PRODUCTIVITY

This appendix gives the method used to estimate the number of haul units required for the hauling activity in earthworks by using the Tractor Trailer Option 1, Flat bed lorry option 1 and the Tipper Truck. These three methods of hauling involve loading by use of mechanical means while unloading is done manually except for the tipper truck which is unloaded mechanically.

To determine the number of haul units required to work with an excavator (bulldozer Option 2), it is necessary to estimate the time required for a haul unit to make one complete cycle. Total cycle time is estimated by summing up the time required for each of the following components of the haul cycle;

(a) Load - at the loader/excavator
(b) Haul - from the loader to unloading site
(c) Dump - at the unloading site including manouvring
(d) Return - travel back to the loader

The estimates are given below.

1. <u>TRACTOR TRAILER OPTION 1</u> (Flat bed lorry Option 1 similar)

<u>Loading Time</u>

Loader Productivity = 86.0 cu.m/hr = 1.43 cu.m/min (chapter 5)

capacity of trailer = 3.0 cu.m

Loading time = 3.0 / 1.43 = 2.1 min

<u>Haul and Return Time</u>

Assuming a travel speed both ways of 20.0 kph (333 m/min) and a haul distance of H metres,

Time to Haul and Return = (2 x H) / 333 min

<u>Dump (or unloading) Time</u>

The productivity for unloading manually by hand tools is 0.03 cu.m / min (de Veen, 1980).

Allowing for 25% losses in productivity, a gang of 8 workers take 15.6 min to unload a 3.0 cu.m trailer load.

Hence total cycle time = [2.1 + (2 x H)/333] x 1.25 + 15.6 minutes

and

Number of units required = Total Cycle Time / Time to Load

Given below in Table A.1 is the result of calculations of number of haul units required for various haul distances using the method outlined above.

Table A.1 Summary of Number of Haul Units required for various Haul Distances

| Haul Dist (m) | 100 | 200 | 500 | 700 | 1000 | 1500 | 2000 |
|---|---|---|---|---|---|---|---|
| Theoretical No of Units Required | 9.0 | 9.4 | 10.5 | 11.2 | 12.3 | 14.0 | 15.8 |

From this set of results, it was assumed that for purposes of this study, a team of 11 tractors with trailers is adequate for hauling when excavating and loading with a bulldozer at a rate of 86.0 cu.m/hr for haul distances of 100 m to 2000 m. A further assumption was that for longer haul distances, higher haul speeds can be achieved hence the extra over 11 units required can be compensated.

2. TIPPER TRUCK

The method followed is the same as that presented above for the tractor trailer option 1. The actual time estimates are presented below.

<u>Loading Time</u>

Loader Productivity = 1.43 cu.m/min

Truck capacity = 4.0 cu.m

Hence Loading Time = 4.0 / 1.43 = 2.8 min

<u>Haul and Return Time</u> (with travel speed of 20 kph)

equals 2 x H / 333 where H is the Haul distance in metres

Dump Time = 3.0 min (HARRIS, 1981)

Hence, Total Cycle Time = [3.0 + (2 x H/333)] x 1.25 + 2.8

and Number of Haul units required

= Total Cycle Time / Loading Time

The results of the above calculations for a number of haul distances are presented below in Table A.2.

Table A.2 The number of Haul Units required for various Haul Distances

| Haul Dist (m) | 200 | 500 | 700 | 1000 | 1500 |
|---|---|---|---|---|---|
| Theoretical number required | 2.8 | 3.6 | 4.2 | 5.0 | 6.4 |

On a similar argument as in the case of the Tractor trailer option discussed above, a team of 4 tipper trucks are considered adequate to work with a bulldozer resulting to a productivity of 86.0 cu.m/hr for haul distances of upto 2000 m.

# APPENDIX B

# UNIT RATES

This appendix shows the unit rates used in this study. The rates shown include a small allowance for overheads (15%) and profit (10%).

I. MATERIALS COST

In situ concrete

Concrete is the only material whose cost is included in this study. The method used to estimate the cost of concrete is as given in ENTERKIN and REYNOLDS (1978) where a 40% increase over the total volume of cement, sand and aggregate is allowed and divided by the total nominal volume of cement, sand and aggregate. This assumes a shrinkage of 28.6% over all materials and is illustrated below;

Concrete Class 1:2:4

| | | | |
|---|---|---|---|
| 1 cu.m Cement, i.e 1.44 Tonnes | @ KSh 1800.00 | = KSh | 2592.00 |
| 2 cu.m Sand, | @ KSh 500.00 | = KSh | 1000.00 |
| 4 cu.m Aggregate | @ KSh 500.00 | = KSh | 2000.00 |
| | Total | = KSh | 5592.00 |
| To allow for shrinkage, add 40% | | = KSh | 7828.80 |
| Hence materials cost of 1 cu.m = KSh 7828/7 | | = KSh | 118.40 |

Concrete Class 1:4:8 (Blinding Concrete)

| | | | |
|---|---|---|---|
| 1 cu.m Cement | @ KSh 1800.00 | = KSh | 2592.00 |
| 4 cu.m Sand | @ KSh 500.00 | = KSh | 2000.00 |
| 8 cu.m Aggregate | @ KSh 500.00 | = KSh | 4000.00 |
| | Total | = KSh | 8592.00 |
| To allow for shrinkage, add 40% | | = KSh | 12028.80 |
| Hence cost of 1 cu.m materials = 12028.00/13 | | = KSh | 925.30 |

For the Three Storeyed Building project, the total cost of reinforcement is KSh 435504.00.

Precast concrete

The cost of 600mm by 600mm by 50mm precast units is KSh 120.00 per square metre.

## II. PLANT AND EQUIPMENT RENTAL RATES

The rates shown below include operator charges and exclude fuel costs.

| Description | Rate (KSh/Hr) |
|---|---|
| Cat D6 Bulldozer with ripper | 720.00 |
| 120 Hp Front Wheel Drive tractor | 460.00 |
| 120 Hp tractor with scraper | 600.00 |
| 145 Hp Wheeldozer with angle blade | 690.00 |
| 125 Hp Grader | 580.00 |
| Agricultural Tractor with trailler | 150.00 |
| Concrete mixer size 10/7 | 290.00 |
| Concrete mixer size 14/10 | 230.00 |
| 5 Ton ordinary lorry | 190.00 |
| 5 Ton tipper lorry | 210.00 |
| 10 to 12 Ton Roller | 260.00 |
| 3 Ton vibrating roller | 150.00 |
| Hand propelled vibrating roller | 70.00 |
| 100 mm Concrete pump | 180.00 |
| 8 Ton mobile crane | 650.00 |
| Hoist | 360.00 |

## III. LABOUR COSTS

Given below are the direct wage rates for the various categories of labour.

| Description | Wage Rate (KSh/Hr) |
|---|---|
| Unskilled Labour | 5.70 |
| General Tradesmen (e.g Masons) | 6.29 |
| Light plant operators | 6.89 |
| Heavy plant operators | 7.54 |
| Drivers | 7.49 |

### Method of calculating Unit Rates

In this section is presented the method of calculation of the unit rates for the various input factors (equipment and labour) at market rates.

Diesel fuel is considered to be used in all power driven equipment. The rate of fuel consumption is based on the following formular (DAY, 1973).

$$\text{Diesel Fuel (gph)} = (0.5 \times \text{bhp} \times \text{Load Factor})/7.2$$
$$= 0.06 \times \text{bhp} \times \text{Load Factor}$$

where the consumption is in gallons per hour (where 1 gallon = 4.536 litres) and bhp is the brake horse power.

Under average operation conditions and for all types of equipment used in this study, a load factor of 0.60 (Day,1973) is assumed. The fuel cost is increased by 20% to allow for oils and grease.

Hence,

Diesel Fuel (Litres/Hr) = 0.06 x 4.536 x 0.6 x bhp

= 0.16 x bhp

Diesel Cost = KSh 6.754/Litre

The indirect labour cost is taken to be 25% of the direct labour cost.

Calculations for the Unit Rates using the bulldozer and the Tractor Trailer option 1 is presented to show how the unit rates shown in Table B.1 are arrived at.

Unit Rate for Bulldozer (all options)

| | |
|---|---|
| Hiring Rate | = KSh 712.46/Hr |
| Skilled Labour (operator) | = KSh 7.54/Hr |
| Indirect Labour rate | = KSh 1.89/Hr |
| Total excluding fuel | = KSh 721.89/Hr |
| Fuel required = 0.16 x 120 = 19.20 litres/Hr | |
| Fuel Cost = 19.20 x 6.754 x 1.2 | = KSh 155.88/Hr |
| Hence Unit Rate | = KSh 877.77/Hr |

Unit Rate for Tractor Trailer option 1 (11 tractors with 11 trailers)

| | | |
|---|---|---|
| Hiring rate for 1 tractor trailer | | = KSh 150.00/Hr |
| Operator wage | | = KSh 6.47/Hr |
| Indirect skilled labour rate | | = KSh 1.62/Hr |
| Unskilled Labour (8 workmen) | = 8 x 5.40 | = KSh 43.20/Hr |
| Indirect Unskilled labour rate | | = KSh 10.80/Hr |
| Total excluding fuel | | = KSh 1793.00/Hr |
| Fuel required = 0.16 x 150 x 11 = 264.00 litres/Hr | | |
| Fuel Cost = 264.00 x 6.574 x 1.2 | | = KSh 2142.84/Hr |
| Hence Unit Rate for Tractor Trailer Option 1 | | = KSh 3935.84/Hr |

The unit rates for all the other input factors are calculated as shown above and are presented in Table B.1 below.

TABLE B.1 A summary of the unit rates (in KSh/Hr) for the input factors for all projects at market rates

Where;

DESCRIPTN: A brief description of the particular input

SL : Skilled Labour rate

USL : Unskilled Labour rate

ER : Equipment rental rate

FC : Fuel cost per hour

TEF : Total excluding fuel

TIF : Total including fuel

| Record# | DESCRIPTN | SL | USL | ER | FC | TEF | TIF |
|---|---|---|---|---|---|---|---|
| 1 | Bulldozer 1 | 9.43 | 0.00 | 712.46 | 155.88 | 721.89 | 877.77 |
| 2 | T/Trailer 1 | 88.99 | 54.00 | 1650.00 | 2142.84 | 1793.00 | 3935.84 |
| 3 | T/Trailer 2 | 8.09 | 110.80 | 150.00 | 194.80 | 268.89 | 463.69 |
| 4 | F/Bed Lorry 1 | 87.50 | 55.40 | 2230.00 | 1948.03 | 2372.90 | 4320.93 |
| 5 | F/Bed Lorry 2 | 8.75 | 110.80 | 223.00 | 194.81 | 342.55 | 537.36 |
| 6 | Tipper Truck | 35.00 | 0.00 | 932.00 | 935.05 | 967.00 | 1902.05 |
| 7 | 125Hp Grader | 9.38 | 0.00 | 572.50 | 162.34 | 581.88 | 744.22 |
| 8 | Hand Tools | 0.00 | 6.89 | 0.00 | 0.00 | 6.89 | 6.89 |
| 9 | 8Ton Self P.Rr | 9.38 | 0.00 | 252.50 | 129.86 | 261.88 | 391.74 |
| 10 | 3.8Ton T.T.Rr | 8.16 | 0.00 | 143.47 | 194.81 | 151.63 | 346.44 |
| 11 | 2Ton Vib.Rr | 8.16 | 0.00 | 283.47 | 25.97 | 291.63 | 317.60 |
| 12 | 200Kg HandP.Rr | 8.16 | 0.00 | 63.47 | 0.00 | 71.63 | 71.63 |
| 13 | 10/7 Mixer | 7.54 | 13.85 | 283.97 | 14.62 | 305.36 | 319.98 |
| 14 | 14/10 Mixer | 7.54 | 20.78 | 223.97 | 18.42 | 252.28 | 270.70 |
| 15 | Concrete Pump | 30.15 | 13.85 | 173.97 | 103.90 | 217.97 | 321.87 |
| 16 | Concrete Hoist | 30.48 | 55.40 | 353.53 | 129.86 | 439.41 | 569.27 |
| 17 | 8Ton Crane | 24.35 | 27.70 | 642.46 | 129.86 | 694.51 | 824.37 |
| 18 | Bulldozer 2 | 9.43 | 0.00 | 712.46 | 155.88 | 721.89 | 877.77 |
| 19 | Bulldozer 3 | 9.43 | 0.00 | 712.46 | 155.88 | 721.89 | 877.77 |
| 20 | Bulldozer 4 | 9.43 | 0.00 | 712.46 | 155.88 | 721.89 | 877.77 |
| 21 | Wheelbarrow | 0.00 | 9.45 | 0.00 | 0.00 | 9.45 | 9.45 |

# APPENDIX C

# INPUT DATA, PROGRAMS LISTING AND OUTPUT DATA

This appendix shows the data used, the programs developed and used and the output data for all the three projects analysed. All the unit rates shown are the market rates. The major works are categorised as either earthworks or concreteworks (as mentioned in chapter 5).

While each project has its own peculiarities, the flow chart given in chapter 6 gives the general principal used in all the programmes.

CI: INPUT DATA

C1: Input data for the "Optimum Programme" to analyse the Gravel Road Project Earthworks

Table C1a: Work details (WORKS database)

| Record# | ACTIVITY | QUANTITY | UNITS | HAUL_DIST |
|---|---|---|---|---|
| 1 | TaskC | 2500.0 | CU.M | 200.0 |
| 2 | TaskD | 9000.0 | CU.M | 1000.0 |

Table C1b: Excavation Equipment details (EXCEQPT database)

| Record# | SHORT | DESCRIPTN | OUTPUT | UNITS | U_RATE | UNIT | U_AVLB | COMP_WITH |
|---|---|---|---|---|---|---|---|---|
| 1 | E1 | Bulldozer 1 | 23.00 | M3/HR | 877.77 | KSh/Hr | 1 | H1 |
| 2 | E2 | Bulldozer 2 | 86.00 | M3/HR | 877.77 | KSh/Hr | 1 | H2,H3,H5 |
| 3 | E3 | Bulldozer 3 | 86.00 | M3/HR | 877.77 | KSh/Hr | 1 | H4,H6,H7 |
| 4 | E4 | Hand Tools | 0.50 | M3/HR | 6.89 | KSh/Hr | 70 | H4,H6,H7 |

Table C1c: Haul equipment details (HAULEQPT database)

| Record# | SHORT | DESCRIPTN | CAP | MAXHAUL | OUTPUT | U_RATE | UNIT | U_AVL | COMP_WITH |
|---|---|---|---|---|---|---|---|---|---|
| 1 | H1 | Bulldozer 1 | 0.0 | 200 | 0.00 | 0.00 | KSh/Hr | 0 | S1 |
| 2 | H2 | Tipper Truck | 3.0 | 4000 | 86.00 | 1902.05 | KSh/Hr | 1 | S7,S8 |
| 3 | H3 | F.Bed Lorry 1 | 4.0 | 3000 | 86.00 | 4320.93 | KSh/Hr | 1 | S2 |
| 4 | H4 | F.Bed Lorry 2 | 4.0 | 3000 | 21.88 | 537.36 | KSh/Hr | 4 | S3 |
| 5 | H5 | T/Trailer 1 | 3.0 | 2000 | 86.00 | 3935.84 | KSh/Hr | 1 | S4 |
| 6 | H6 | T/Trailer 2 | 3.0 | 2000 | 2.70 | 463.69 | KSh/Hr | 7 | S5 |
| 7 | H7 | Wheelbarrow | 0.1 | 200 | 0.10 | 9.45 | KSh/Hr | 70 | S6 |

Table C1d: Spreading Equipment details (SPREADEQ database)

| Record# | SHORT | DESCRIPTN | OUTPUT | UNIT | U_RATE | UNITS | U_AVLB | COMP_WITH |
|---|---|---|---|---|---|---|---|---|
| 1 | S1 | Bulldozer 1 | 0.0 | M3/HR | 0.00 | KSh/Hr | 0 | C1,C2,C3,C4 |
| 2 | S2 | F.Bed Lorry 1 | 0.0 | M3/HR | 0.00 | KSh/Hr | 0 | C1,C2,C3,C4 |
| 3 | S3 | F.Bed Lorry 2 | 0.0 | M3/HR | 0.00 | KSh/Hr | 0 | C1,C2,C3,C4 |
| 4 | S4 | T/Trailer 1 | 0.0 | M3/HR | 0.00 | KSh/Hr | 0 | C1,C2,C3,C4 |
| 5 | S5 | T/Trailer 2 | 0.0 | M3/HR | 0.00 | KSh/Hr | 0 | C1,C2,C3,C4 |
| 6 | S6 | Wheelbarrow | 0.0 | M3/HR | 0.00 | KSh/Hr | 0 | C1,C2,C3,C4 |
| 7 | S7 | 125Hp Grader | 115.0 | M3/HR | 744.22 | KSh/Hr | 1 | C1,C2,C3,C4 |
| 8 | S8 | Hand Tools | 1.5 | M3/HR | 6.89 | KSh/Hr | 50 | C1,C2,C3,C4 |

Table C1e: Compacting Equipment details (COMPEQPT database)

| Record# | SHORT | DESCRIPTN | OUTPUT | UNITS | U_RATE | UNIT | U_AVLB |
|---|---|---|---|---|---|---|---|
| 1 | C1 | 8Ton Self P.Rr | 118.0 | M3/HR | 391.74 | KSh/Hr | 1 |
| 2 | C2 | 3.8Ton T.T.Rr | 108.0 | M3/HR | 346.44 | KSh/Hr | 1 |
| 3 | C3 | 2Ton Vib.Rr | 46.2 | M3/HR | 317.60 | KSh/Hr | 2 |
| 4 | C4 | 200Kg HandP.Rr | 2.2 | M3/HR | 71.63 | KSh/Hr | 6 |

C2: Input Data for the "Building Program" to analyse the 3 Storeyed Building Project Earthworks

Table C2a: Work details (WORKS2 database)

| Record# | ACTIVITY | QUANTITY | UNITS | HAUL_DIST | COMP_WITH |
|---|---|---|---|---|---|
| 1 | Job1 | 356.0 | CU.M | 200.0 | E1,E2,E3,E4 |
| 2 | Job2 | 890.0 | CU.M | 200.0 | E1,E2,E3,E4 |
| 3 | Job3 | 1690.0 | CU.M | 0.0 | E5 |

Table C2b: Excavation Equipment details (EXCEQ2 database)

| Record# | SHORT | DESCRIPTN | OUTPUT | UNITS | U_RATE | UNIT | U_AVLB | COMP_WITH |
|---|---|---|---|---|---|---|---|---|
| 1 | E1 | Bulldozer 1 | 23.00 | M3/HR | 877.77 | KSh/Hr | 1 | H1 |
| 2 | E2 | Bulldozer 2 | 86.00 | M3/HR | 877.77 | KSh/Hr | 1 | H2,H3,H5 |
| 3 | E3 | Bulldozer 3 | 86.00 | M3/HR | 877.77 | KSh/Hr | 1 | H4,H6,H7 |
| 4 | E4 | Hand Tools | 0.50 | M3/HR | 6.89 | KSh/Hr | 70 | H4,H6,H7 |
| 5 | E5 | Bulldozer 4 | 86.00 | M3/HR | 877.77 | KSh/Hr | 1 | H8 |

Table C2c: Hauling Equipment details (HAULEQ2 database)

| Record# | SHORT | DESCRIPTN | CAP | MAXHAUL | OUTPUT | U_RATE | UNIT | U_AVLB |
|---|---|---|---|---|---|---|---|---|
| 1 | H1 | Bulldozer 1 | 0.0 | 200.0 | 0.00 | 0.00 | KSh/Hr | 0 |
| 2 | H2 | Tipper Truck | 3.0 | 4000.0 | 86.00 | 1902.05 | KSh/Hr | 1 |
| 3 | H3 | F.Bed Lorry 1 | 4.0 | 3000.0 | 86.00 | 4320.93 | KSh/Hr | 1 |
| 4 | H4 | F.Bed Lorry 2 | 4.0 | 3000.0 | 0.00 | 537.36 | KSh/Hr | 7 |
| 5 | H5 | T/Trailer 1 | 3.0 | 2000.0 | 86.00 | 3935.84 | KSh/Hr | 1 |
| 6 | H6 | T/Trailer 2 | 3.0 | 2000.0 | 3.20 | 463.69 | KSh/Hr | 7 |
| 7 | H7 | Wheelbarrow | 0.1 | 200.0 | 3.19 | 9.45 | KSh/Hr | 70 |
| 8 | H8 | Bulldozer 4 | 0.0 | 0.0 | 0.00 | 0.00 | KSh/Hr | 0 |

C3: Input Data for the "Concopt Program" to analyse the 3 Storeyed Building Project Concreteworks

Table C3a: Work details (CONCWORK database)

| Record# | ACTIVITY | QUANTITY | UNITS | COMP_WITH |
|---|---|---|---|---|
| 1 | JobA | 86.00 | m3 | CH1,CH2 |
| 2 | JobB | 340.00 | m3 | CH1,CH2 |
| 3 | JobC | 170.00 | m3 | CH1,CH2 |
| 4 | JobD | 687.00 | m3 | CH1,CH2,CH3,CH4 |

Table C3b: Mixing Equipment details (CONCMIX database)

| Record# | SHORT | DESCRIPTN | PRODTN | UNITS | U_RATE | UNIT | U_AVLB | COMP_WITH |
|---|---|---|---|---|---|---|---|---|
| 1 | CM1 | 10/7 mixer | 2.00 | m3/hr | 319.98 | Ksh/Hr | 4 | CH1,CH2,CH3,CH4 |
| 2 | CM2 | 14/10 Mixer | 2.80 | m3/hr | 270.70 | Ksh/Hr | 4 | CH1,CH2,CH3,CH4 |

Table C3c: Hauling Equipment details (CONCHAUL database)

| Record# | SHORT | DESCRIPTN | PRODTN | UNITS | U_RATE | UNIT | U_AVLB |
|---|---|---|---|---|---|---|---|
| 1 | CH1 | wheelbarrow | 0.70 | m3/hr | 9.45 | Ksh/Hr | 10 |
| 2 | CH2 | concrete pump | 22.00 | m3/hr | 321.87 | Ksh/Hr | 1 |
| 3 | CH3 | concrete hoist | 11.40 | m3/hr | 569.27 | Ksh/Hr | 1 |
| 4 | CH4 | 8Ton crane | 4.20 | m3/hr | 824.37 | Ksh/Hr | 1 |

C4: Input Data for the "Ponds Program" to analyse the Oxidation Ponds Project Earthworks

Table C4a: Work details (WORKS3 database)

| Record# | ACTIVITY | QUANTITY | UNITS | HAUL_DIST |
|---|---|---|---|---|
| 1 | Task1 | 4080.0 | CU.M | 1500.0 |
| 2 | Task2 | 20000.0 | CU.M | 175.0 |
| 3 | Task3 | 7932.0 | CU.M | 2000.0 |

Table C4b: Excavation Equipment details (EXCEQ3 database)

| Record# | SHORT | DESCRIPTN | OUTPUT | UNITS | U_RATE | UNIT | U_AVLB | COMP_WITH |
|---|---|---|---|---|---|---|---|---|
| 1 | E1 | Bulldozer 1 | 23.00 | M3/HR | 877.77 | KSh/Hr | 3 | H1 |
| 2 | E2 | Bulldozer 2 | 86.00 | M3/HR | 877.77 | KSh/Hr | 3 | H2,H3,H5 |
| 3 | E3 | Bulldozer 3 | 86.00 | M3/HR | 877.77 | KSh/Hr | 3 | H4,H6,H7 |
| 4 | E4 | Hand Tools | 0.50 | M3/HR | 6.89 | KSh/Hr | 300 | H4,H6,H7 |

Table C4c: Hauling Equipment details (HAULEQ3 database)

| Record# | SHORT | DESCRIPTN | CAPACITY | MAXHAUL_M | OUTPUT | U_RATE | UNIT | U_AVLB |
|---|---|---|---|---|---|---|---|---|
| 1 | H1 | Bulldozer 1 | 0.0 | 200.0 | 0.00 | 0.00 | KSh/Hr | 0 |
| 2 | H2 | Tipper Truck | 3.0 | 4000.0 | 86.00 | 1902.05 | KSh/Hr | 3 |
| 3 | H3 | F.Bed Lorry 1 | 4.0 | 3000.0 | 86.00 | 4320.93 | KSh/Hr | 3 |
| 4 | H4 | F.Bed Lorry 2 | 4.0 | 3000.0 | 16.84 | 537.36 | KSh/Hr | 9 |
| 5 | H5 | T/Trailer 1 | 3.0 | 2000.0 | 86.00 | 3935.84 | KSh/Hr | 3 |
| 6 | H6 | T/Trailer 2 | 3.0 | 2000.0 | 2.45 | 463.69 | KSh/Hr | 9 |
| 7 | H7 | Wheelbarrow | 0.1 | 200.0 | 0.07 | 9.45 | KSh/Hr | 300 |

C5: Input Data for the "Concpond Program" to analyse the Oxidation Ponds Project Concreteworks

Table C5a: Work details (PONDCONC database)

| Record# | ACTIVITY | QUANTITY | UNITS |
|---|---|---|---|
| 1 | JobA | 803.00 | m3 |

Table C5b: Mixing Equipment details (PONDMIX database)

| Record# | SHORT | DESCRIPTN | PRODTN | UNITS | U_RATE | UNIT | U_AVLB | COMP_WITH |
|---|---|---|---|---|---|---|---|---|
| 1 | CM1 | 10/7 mixer | 2.00 | m3/hr | 319.98 | Ksh/Hr | 4 | CH1,CH2 |
| 2 | CM2 | 14/10 Mixer | 2.80 | m3/hr | 270.70 | Ksh/Hr | 4 | CH1,CH2 |

Table C5c: Hauling Equipment details (PONDHAUL database)

| Record# | SHORT | DESCRIPTN | PRODTN | UNITS | U_RATE | UNIT | U_AVLB |
|---|---|---|---|---|---|---|---|
| 1 | CH1 | wheelbarrow | 0.70 | m3/hr | 9.45 | Ksh/Hr | 10 |
| 2 | CH2 | concrete pump | 22.00 | m3/hr | 321.87 | Ksh/Hr | 1 |

PROGRAM LISTING

```
*********************************************************
*  OPTIMUM PROGRAM                                      *
*  For the Gravel Road Project Earthworks               *
*  By Kagiri, M.G.
*********************************************************
*  This program calculates the costs of carrying out    *
*  the activities in WORKS dbf by considering all the   *
*  possible combinations of Excavation, Haul and        *
*  Compaction equipment whose details are extracted     *
*  from their respective db files. The minimum cost is  *
*  also established.                                    *
*********************************************************
?
CLOSE ALL
SET TALK OFF

USE works INDEX works

IF EOF()
EXIT
ELSE

DO WHILE .NOT. EOF()

ACTCOST=0
MINCOST=999999
?
? ACTIVITY
? QUANTITY

SELECT B
USE exceqpt INDEX exceqpt

DO WHILE .NOT. EOF()
* Find below the unit rate,units available and productivity
* of the excavating equipment
  UREXC=U_RATE
  UAEXC=U_AVLB
  PRODEXC=OUTPUT

IF EOF()
  EXIT
  ELSE

?
SELECT C

USE hauleqpt INDEX hauleqpt

DO WHILE .NOT. EOF()

DO CASE

CASE TRIM(c->short) $ 'H4'          && F.Bed Lorry 2
  prodtn=exp(7.541-0.645*log(a->haul_dist))
  REPLACE c->output WITH prodtn


CASE TRIM(c->short) $ 'H6'           && T/Trailer 2
   prodtn=3.2-0.0005*a->haul_dist
   REPLACE c->output WITH prodtn
```

```
CASE TRIM(c->short) $ 'H7'            && Wheelbarrow
  prodtn=1/(0.313+0.0095*a->haul_dist)
  REPLACE c->output WITH prodtn

  ENDCASE

* This is the unit rate,units available and productivity
* of the hauling equipment
IF TRIM(short) $ b->comp_with .AND. c->maxhaul>= a->haul_dist

   URHAUL=u_rate
   UAHAUL=u_avl
   PRODHAUL=output
   ELSE
   SKIP
   LOOP
 ENDIF

?
SELECT D

USE spreadeq INDEX spreadeq

DO WHILE .NOT. EOF()
IF TRIM(short) $ c->comp_with
   URSPREAD=d->u_rate
   UASPREAD=d->u_avlb
   PRODSPREAD=d->output
   ELSE
   SKIP
   LOOP
 ENDIF

?
SELECT E

USE compeqpt INDEX compeqpt

DO WHILE .NOT. EOF()
* Find below the unit rate,units available and productivity
* of the compacting equipment
 IF trim(SHORT) $ d->COMP_WITH
    URCOMP=e->u_rate
    UACOMP=e->u_avlb
    PRODCOMP=e->output
    ELSE
    SKIP
   LOOP
  ENDIF
?

?'COMPACT WITH',e->descriptn,'SPREAD WITH',d->descriptn,;
 'HAUL WITH',c->descriptn,'EXCAVATE WITH',b->descriptn


* Shown below is the calculation of durations

EXCTIME=a->quantity/(prodexc*uaexc)

STORE exctime TO maxtime1

 IF urhaul=0 .OR.uahaul=0 .OR.prodhaul=0
```

```
    HAULTIME=0
     ELSE
       HAULTIME=a->quantity/(prodhaul*uahaul)
    ENDIF

STORE haultime TO maxtime2

STORE MAX(maxtime1,maxtime2) TO maxtime3

  IF urspread=0 .OR. uaspread=0 .OR. prodspread=0
   SPREADTIME=0
    ELSE
     SPREADTIME=a->quantity/(prodspread*uaspread)
     ENDIF

STORE spreadtime TO maxtime4

STORE MAX(maxtime3,maxtime4) TO maxtime5


COMPTIME=a->quantity/(prodcomp*uacomp)

STORE comptime TO maxtime6

STORE MAX(maxtime5,maxtime6) TO acttime


? 'ACTTIME IS',acttime,'HRS'

* Shown below is the calculation of the costs

IF TRIM(b->short) $ 'E3'
 EXCCOST=urexc*exctime*uaexc
  ELSE
  EXCCOST=urexc*acttime*uaexc
  ENDIF

IF urhaul=0 .OR. uahaul=0 .OR. prodhaul=0
  HAULCOST=0
   ELSE
  HAULCOST=urhaul*acttime*uahaul
   ENDIF

IF urspread=0 .OR. uaspread=0 .OR. prodspread=0
  SPREADCOST=0
   ELSE
  SPREADCOST=urspread*acttime*uaspread
  ENDIF

COMPCOST=urcomp*acttime*uacomp

ACTCOST=EXCCOST+HAULCOST+SPREADCOST+COMPCOST

?compcost,spreadcost,haulcost,exccost,actcost
?comptime,spreadtime,haultime,exctime,acttime



? 'THE MINIMUM COST SO FAR IS'
STORE MIN(ACTCOST,mincost) TO mincost

SELECT F
```

```
USE summary1

INSERT AUTOMEM


REPLACE jobpart WITH a->activity
REPLACE eeq WITH b->short, etime WITH exctime, heq WITH c->short,;
htime WITH haultime, seq WITH d->short, stime WITH spreadtime,;
ceq WITH e->short, ctime WITH comptime, jobtime WITH acttime,;
jobcost WITH actcost

SELECT E

* The IF..ENDIF following helps to keep track of the least cost
* combination of equipment for a particular task.

bestcomp=0
bestspread=0
besthaul=0
bestexc=0
IF actcost <= mincost
 mincost=actcost
 bestcomp=e->descriptn
 bestspread=d->descriptn
 besthaul=c->descriptn
 bestexc=b->descriptn
? bestcomp,bestspread,besthaul,bestexc
 ENDIF

**WAIT
ENDIF
?
IF EOF()
 EXIT
 ELSE
 SKIP
 LOOP
ENDIF
ENDDO     && E LOOP

SELECT D

IF EOF()
 EXIT
 ELSE
 SKIP
 LOOP
ENDIF
ENDDO   && D LOOP


SELECT C

IF EOF()
 EXIT
 ELSE
 SKIP
 LOOP
ENDIF

ENDDO  && C LOOP

?'MINIMUM COST OF', a->activity, mincost
```

```
?'COST ANALYSIS FOR POSSIBLE COMBINATIONS WITH'
? b->descriptn,'HAS BEEN COMPLETED'

SELECT B

IF EOF()
EXIT
ELSE
SKIP
LOOP
ENDIF


ENDDO  && B LOOP

**WAIT

SELECT A

IF EOF()
EXIT
ELSE
SKIP
LOOP
ENDIF

ENDIF

ENDDO  && A LOOP

ENDIF

**WAIT
RETURN
```

```
**************************************************************
*  BUILDING PROGRAM                                          *
*  For the Three Storeyed Building Earthworks                *
*  By Kagiri M.G.                                            *
**************************************************************
*  This program calculates the costs of carrying out         *
*  the activities in WORKS2 dbf by considering all the       *
*  possible combinations of Excavation and Haul              *
*  equipment whose details are extracted from their          *
*  respective db files. The minimum cost is                  *
*  also established.                                         *
**************************************************************
?
CLOSE ALL
SET TALK OFF

SELECT A

USE works2 INDEX works2

IF EOF()
EXIT
ELSE

DO WHILE .NOT. EOF()

ACTCOST=0
MINCOST=999999
?
? ACTIVITY
? QUANTITY

SELECT B

USE exceq2 INDEX exceq2

DO WHILE .NOT. EOF()
If TRIM (Short) $ a->comp_with
* Find below the unit rate,units available and productivity
* of the excavating equipment
  UREXC=U_RATE
  UAEXC=U_AVLB
  PRODEXC=OUTPUT

  ELSE
  SKIP
  LOOP
 ENDIF

?
SELECT C

USE hauleq2 INDEX hauleq2

DO WHILE .NOT. EOF()

DO CASE

CASE TRIM(c->short) $ 'H4'          && F.Bed Lorry 2
  prodtn=exp(7.541-0.645*log(a->haul_dist))
  REPLACE c->output WITH prodtn
```

```
CASE TRIM(c->short) $ 'H6'          && T/Trailer 2
  prodtn=3.2-0.0005*a->haul_dist
  REPLACE c->output WITH prodtn

CASE TRIM(c->short) $ 'H7'          && Wheelbarrow
  prodtn=1/(0.313+0.0095*a->haul_dist)
  REPLACE c->output WITH prodtn

ENDCASE

* This is the unit rate,units available and productivity
* of the hauling equipment
IF TRIM(c->short) $ b->comp_with .AND. c->maxhaul >= a->haul_dist

   URHAUL=U_RATE
   UAHAUL=U_AVLB
   PRODHAUL=OUTPUT
   ELSE
   SKIP
   LOOP
 ENDIF
?
?'HAUL WITH',c->descriptn,'EXCAVATE WITH',b->descriptn

* Shown below is the calculation of durations

EXCTIME=a->quantity/(prodexc*uaexc)

STORE exctime TO maxtime1

 IF urhaul=0 .OR. uahaul=0 .OR. prodhaul=0
    HAULTIME=0
     ELSE
       HAULTIME=a->quantity/(prodhaul*uahaul)
    ENDIF

STORE haultime TO maxtime2

STORE MAX(maxtime1,maxtime2) TO acttime

? 'ACTTIME IS',acttime,'HRS'

* Shown below is the calculation of the costs

IF TRIM(b->short) $ 'E3'
 EXCCOST=urexc*exctime*uaexc
  ELSE
  EXCCOST=urexc*acttime*uaexc
  ENDIF

IF urhaul=0 .OR. uahaul=0 .OR. prodhaul=0
  HAULCOST=0
   ELSE
  HAULCOST=urhaul*acttime*uaexc
   ENDIF

ACTCOST=exccost+haulcost

?HAULCOST,EXCCOST,ACTCOST
?HAULTIME,EXCTIME,ACTTIME
```

```
? 'THE MINIMUM COST SO FAR IS'
STORE MIN(ACTCOST,mincost) TO mincost

SELECT D

USE summary2

INSERT AUTOMEM
REPLACE jobpart WITH a->activity
REPLACE exceq WITH b->short, etime WITH exctime, hauleq WITH c->short,;
htime WITH haultime
REPLACE jobtime WITH acttime, jobcost WITH actcost

SELECT C

* The IF..ENDIF following helps to keep track of the cheapest
* combination of equipment

besthaul=0
bestexc=0
IF actcost <= mincost
 mincost=actcost
 besthaul=c->descriptn
 bestexc=b->descriptn
? besthaul,bestexc
 ENDIF

**WAIT
ENDIF

IF EOF()
 EXIT
 ELSE
 SKIP
 LOOP
ENDIF

ENDDO   && C LOOP

?'MINIMUM COST OF', a->activity, mincost
?'COST ANALYSIS FOR POSSIBLE COMBINATIONS WITH'
? b->descriptn,'HAS BEEN COMPLETED'

SELECT B

IF EOF()
 EXIT
 ELSE
 SKIP
 LOOP
ENDIF

ENDDO  && B LOOP

**WAIT

SELECT A

IF EOF()
 EXIT
 ELSE
 SKIP
 LOOP
```

```
ENDIF

ENDIF

ENDDO  && A LOOP

ENDIF

**WAIT
RETURN
```

```
*********************************************************
*  CONCOPT PROGRAM                                      *
*  For The Three Storeyed Building Concreteworks        *
*  By Kagiri M.G.                                       *
*********************************************************
*  This program calculates the costs and durations      *
*  of carrying out the activities in CONCWORKS dbf      *
*  by considering all the possible combinations of      *
*  Mixing and Haul equipment whose details are          *
*  extracted  from their from their respective db       *
*  files. The minimum cost for a particular task is     *
*  also established.                                    *
*********************************************************
?
CLOSE ALL
SET TALK OFF

USE concwork INDEX concwork

IF EOF()
EXIT
ELSE

DO WHILE .NOT. EOF()

ACTCOST=0
MINCOST=999999
?
? ACTIVITY
? QUANTITY

SELECT B

USE concmix INDEX concmix

DO WHILE .NOT. EOF()
* Find below the unit rate,units available and productivity
* of the MIXING equipment
  URMIX=U_RATE
  UAMIX=U_AVLB
  PRODMIX=PRODTN
  IF EOF()
  EXIT
  SELECT A
  ELSE
?
SELECT C

USE conchaul INDEX conchaul

DO WHILE .NOT. EOF()
* This is the unit rate,units available and productivity
* of the hauling equipment
 IF TRIM(short) $ b->comp_with .AND. TRIM(short) $ a->comp_with
   URHAUL=U_RATE
   UAHAUL=U_AVLB
   PRODHAUL=PRODTN
   ELSE
   SKIP
   LOOP
   ENDIF
?
```

```
?'HAUL WITH',c->descriptn,',MIX WITH',b->descriptn

* Costs of excavation,hauling,compaction and total cost for
* activity and combination considered are given below
?
MIXTIME=a->quantity/(prodmix*uamix)
HAULTIME=a->quantity/(prodhaul*uahaul)
ACTTIME=MAX(mixtime,haultime)

? 'ACTTIME IS',acttime,'HRS'

MIXCOST=urmix*acttime*uamix
HAULCOST=urhaul*acttime*uahaul
ACTCOST=mixcost+haulcost

?HAULCOST,MIXCOST,ACTCOST
? 'THE MINIMUM COST SO FAR IS'
STORE MIN(actcost,mincost) TO mincost
?? m->mincost

SELECT D

USE summary4

INSERT AUTOMEM
REPLACE jobpart WITH a->activity, mixeq WITH b->short, mtime WITH mixtime,;
hauleq WITH c->short, htime WITH haultime, jobtime WITH acttime,;
jobcost WITH actcost

SELECT C

*The IF..ENDIF following helps to keep track of the most
*optimum combination of equipment

besthaul=0
bestMIX=0
IF actcost <= mincost
 mincost=actcost
 besthaul=c->descriptn
 bestmix=b->descriptn
? besthaul,bestmix
 ENDIF

**WAIT
ENDIF
?
IF EOF()
 EXIT
 ELSE
 SKIP
 LOOP
ENDIF

ENDDO  && C LOOP

?'MINIMUM COST OF', a->activity, mincost
?'COST ANALYSIS FOR POSSIBLE COMBINATIONS WITH'
? b->descriptn,'HAS BEEN COMPLETED'

SELECT B

IF EOF()
 EXIT
 ELSE
```

```
 SKIP
 LOOP
ENDIF

ENDDO  && B LOOP

**WAIT

SELECT A

IF EOF()
 EXIT
 ELSE
 SKIP
 LOOP
ENDIF

ENDDO  && A LOOP

ENDIF

**WAIT
RETURN
```

```
**********************************************************
*  PONDS PROGRAM                                         *
*  For The Oxidation Ponds Project Earthworks            *
*  By Kagiri M.G.                                        *
**********************************************************
*  This program calculates the costs of carrying out     *
*  the activities in WORKS3 dbf by considering all the   *
*  possible combinations of Excavation and Haul          *
*  equipment whose details are extracted from their      *
*  respective db files. The minimum cost is also         *
*  established.                                          *
**********************************************************
?
CLOSE ALL
SET TALK OFF

USE works3 INDEX works3

IF EOF()
EXIT
ELSE

DO WHILE .NOT. EOF()

ACTCOST=0
MINCOST=999999
?
? ACTIVITY
? QUANTITY

SELECT B

USE exceq3 INDEX exceq3

DO WHILE .NOT. EOF()
* Find below the unit rate,units available and productivity
* of the excavating equipment
  UREXC=U_RATE
  UAEXC=U_AVLB
  PRODEXC=OUTPUT

 IF EOF()
  EXIT
  SELECT A
   ELSE
?
SELECT C

USE hauleq3 INDEX hauleq3

DO WHILE .NOT. EOF()

DO CASE

CASE TRIM(c->short) $ 'H4'          && F.Bed Lorry 2
  prodtn=exp(7.541-0.645*log(a->haul_dist))
  REPLACE output WITH prodtn

CASE TRIM(c->short) $ 'H6'          && T/Trailer 2
  prodtn=3.2-0.0005*a->haul_dist
  REPLACE c->output WITH prodtn
```

```
CASE TRIM(c->short) $ 'H7'           && Wheelbarrow
  prodtn=1/(0.313+0.0095*a->haul_dist)
  REPLACE c->output WITH prodtn

  ENDCASE

* This is the unit rate,units available and productivity
* of the hauling equipment
IF TRIM(short) $ b->comp_with .AND. c->maxhaul_m >= a->haul_dist

   URHAUL=U_RATE
   UAHAUL=U_AVLB
   PRODHAUL=OUTPUT
   ELSE
   SKIP
   LOOP
 ENDIF
?
?'HAUL WITH',c->descriptn,'EXCAVATE WITH',b->descriptn

* Shown below is the calculation of durations

EXCTIME=a->quantity/(prodexc*uaexc)

STORE exctime TO maxtime1

 IF urhaul=0 .OR.uahaul=0 .OR.prodhaul=0
    HAULTIME=0
     ELSE
       HAULTIME=a->quantity/(prodhaul*uahaul)
    ENDIF

STORE haultime TO maxtime2

STORE MAX(maxtime1,maxtime2) TO acttime

? 'ACTTIME IS',acttime,'HRS'

* Shown below is the calculation of the costs

IF TRIM(b->short) $ 'E3'
  EXCCOST=urexc*exctime*uaexc
  ELSE
  EXCCOST=urexc*acttime*uaexc
  ENDIF

IF urhaul=0 .OR. uahaul=0 .OR. prodhaul=0
  HAULCOST=0
   ELSE
  HAULCOST=urhaul*acttime*uahaul
   ENDIF

ACTCOST=exccost+haulcost

?HAULCOST,EXCCOST,ACTCOST
?HAULTIME,EXCTIME,ACTTIME



? 'THE MINIMUM COST SO FAR IS'
STORE MIN(actcost,mincost) TO mincost

SELECT D
```

```
USE summary3

INSERT AUTOMEM
REPLACE jobpart WITH a->activity
REPLACE exceq WITH b->short, etime WITH exctime,;
hauleq WITH c->short, htime WITH haultime
REPLACE jobtime WITH acttime, jobcost WITH actcost

SELECT C

* The IF..ENDIF following helps to keep track of the cheapest
* combination of equipment

besthaul=0
bestexc=0
IF actcost <= mincost
 mincost=actcost
 besthaul=c->descriptn
 bestexc=b->descriptn
? besthaul,bestexc
 ENDIF

**WAIT
ENDIF
?
IF EOF()
 EXIT
 ELSE
 SKIP
 LOOP
ENDIF

ENDDO  && C LOOP

?'MINIMUM COST OF', a->activity, mincost
?'COST ANALYSIS FOR POSSIBLE COMBINATIONS WITH'
? b->descriptn,'HAS BEEN COMPLETED'

SELECT B

IF EOF()
 EXIT
 ELSE
 SKIP
 LOOP
ENDIF

ENDDO  && B LOOP

**WAIT

SELECT A

IF EOF()
 EXIT
 ELSE
 SKIP
 LOOP
ENDIF

ENDIF

ENDDO  && A LOOP
```

```
ENDIF

**WAIT
RETURN
```

```
*************************************************************
*  CONCPOND PROGRAM                                         *
*  For the Oxidation Ponds Project Concreteworks            *
*  By Kagiri M.G.                                           *
*************************************************************
*  This program calculates the costs and durations of       *
*  carrying out the activities in PONDWORK dbf by           *
*  considering all the possible combinations of Mixing      *
*  and Haul equipment whose details are extracted           *
*  from their respective db files. The minimum cost is      *
*  also established.                                        *
*************************************************************
?
CLOSE ALL
SET TALK OFF

USE pondconc INDEX pondconc

IF EOF()
EXIT
ELSE

DO WHILE .NOT. EOF()

ACTCOST=0
MINCOST=999999
?
? ACTIVITY
? QUANTITY

SELECT B

USE pondmix INDEX pondmix

DO WHILE .NOT. EOF()
* Find below the unit rate,units available and productivity
* of the MIXING equipment

  URMIX=U_RATE
  UAMIX=U_AVLB
  PRODMIX=PRODTN

  IF EOF()
  EXIT
  SELECT A
  ELSE
?
SELECT C
USE pondhaul INDEX pondhaul

DO WHILE .NOT. EOF()
* This is the unit rate,units available and productivity
* of the hauling equipment

 IF TRIM(short) $ b->comp_with
   URHAUL=U_RATE
   UAHAUL=U_AVLB
   PRODHAUL=PRODTN
   ELSE
   SKIP
   LOOP
  ENDIF
```

```
?
?'HAUL WITH',c->descriptn,',MIX WITH',b->descriptn

* Costs of excavation,hauling,compaction and total cost for
* activity and combination considered are given below.
?
MIXTIME=a->quantity/(prodmix*uamix)
HAULTIME=a->quantity/(prodhaul*uahaul)
ACTTIME=MAX(mixtime,haultime)

? 'ACTTIME IS',acttime,'HRS'

MIXCOST=urmix*acttime*uamix
HAULCOST=urhaul*acttime*uahaul
ACTCOST=mixcost+haulcost

?HAULCOST,MIXCOST,ACTCOST
? 'THE MINIMUM COST SO FAR IS'
STORE MIN(actcost,mincost) TO mincost
?? m->mincost

SELECT D

USE summary5

INSERT AUTOMEM
REPLACE jobpart WITH a->activity, mixeq WITH b->short, mtime WITH mixtime,;
hauleq WITH c->short, htime WITH haultime, jobtime WITH acttime,;
jobcost WITH actcost

SELECT C

*The IF..ENDIF following helps to keep track of the most
*optimum combination of equipment

besthaul=0
bestmix=0
IF actcost <= mincost
 mincost=actcost
 besthaul=c->descriptn
 bestmix=b->descriptn
? besthaul,bestmix
 ENDIF

**WAIT
ENDIF
?
IF EOF()
EXIT
ELSE
SKIP
LOOP
ENDIF

ENDDO  && C LOOP

?'MINIMUM COST OF', a->activity, mincost
?'COST ANALYSIS FOR POSSIBLE COMBINATIONS WITH'
? b->descriptn,'HAS BEEN COMPLETED'

SELECT B

IF EOF()
EXIT
```

```
ELSE
SKIP
LOOP
ENDIF

ENDDO  && B LOOP

**WAIT

SELECT A

IF EOF()
EXIT
ELSE
SKIP
LOOP
ENDIF

ENDDO  && B LOOP

ENDIF

**WAIT
RETURN
```

CIII OUTPUT DATA

Results obtained by using the programmes listed in section CII and the Input Data presented in section CI are given below in Tables CIIIa to CIIIe. This is the typical data from which the various durations and costs for the different tasks for each project is obtained (as summarised in Tables 7.1 to 7.10 in chapter 7).

The particular data obtained here is at market rates. For costs at shadow rates, the market unit rates are multiplied by the appropriate shadow ratios (as given in chapter 4 and appendix B) and the new costs obtained.

Table CIIIa: Durations and costs for the viable methods of construction for the Gravel Road Project Earthworks (SUMMARY1 database)

| Record# | JOBPART | EEQ | ETIME | HEQ | HTIME | SEQ | STIME | CEQ | CTIME | JOBTIME | JOBCOST | CLASS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | TaskD | E4 | 257.1 | H6 | 476.2 | S5 | 0.00 | C4 | 681.8 | 681.82 | 2834938.64 | IL |
| 2 | TaskD | E4 | 257.1 | H6 | 476.2 | S5 | 0.00 | C3 | 97.40 | 476.19 | 2077776.19 | IL |
| 3 | TaskD | E4 | 257.1 | H6 | 476.2 | S5 | 0.00 | C2 | 83.33 | 476.19 | 1940271.43 | IL |
| 4 | TaskD | E4 | 257.1 | H6 | 476.2 | S5 | 0.00 | C1 | 76.27 | 476.19 | 1961842.86 | IL |
| 5 | TaskD | E4 | 257.1 | H4 | 102.8 | S3 | 0.00 | C4 | 681.8 | 681.82 | 2087400.00 | IL |
| 6 | TaskD | E4 | 257.1 | H4 | 102.8 | S3 | 0.00 | C3 | 97.40 | 257.14 | 840070.29 | IL |
| 7 | TaskD | E4 | 257.1 | H4 | 102.8 | S3 | 0.00 | C2 | 83.33 | 257.14 | 765817.71 | IL |
| 8 | TaskD | E4 | 257.1 | H4 | 102.8 | S3 | 0.00 | C1 | 76.27 | 257.14 | 777466.29 | IL |
| 9 | TaskD | E3 | 104.7 | H6 | 476.2 | S5 | 0.00 | C4 | 681.8 | 681.82 | 2597957.38 | IC |
| 10 | TaskD | E3 | 104.7 | H6 | 476.2 | S5 | 0.00 | C3 | 97.40 | 476.19 | 1939969.17 | IC |
| 11 | TaskD | E3 | 104.7 | H6 | 476.2 | S5 | 0.00 | C2 | 83.33 | 476.19 | 1802464.41 | IC |
| 12 | TaskD | E3 | 104.7 | H6 | 476.2 | S5 | 0.00 | C1 | 76.27 | 476.19 | 1824035.84 | IC |
| 13 | TaskD | E3 | 104.7 | H4 | 102.8 | S3 | 0.00 | C4 | 681.8 | 681.82 | 1850418.74 | IC |
| 14 | TaskD | E3 | 104.7 | H4 | 102.8 | S3 | 0.00 | C3 | 97.40 | 104.65 | 383275.47 | IC |
| 15 | TaskD | E3 | 104.7 | H4 | 102.8 | S3 | 0.00 | C2 | 83.33 | 104.65 | 353056.40 | IC |
| 16 | TaskD | E3 | 104.7 | H4 | 102.8 | S3 | 0.00 | C1 | 76.27 | 104.65 | 357797.09 | IC |
| 17 | TaskD | E2 | 104.7 | H5 | 104.7 | S4 | 0.00 | C4 | 681.8 | 681.82 | 3575038.64 | IC |
| 18 | TaskD | E2 | 104.7 | H5 | 104.7 | S4 | 0.00 | C3 | 97.40 | 104.65 | 570224.30 | CI |
| 19 | TaskD | E2 | 104.7 | H5 | 104.7 | S4 | 0.00 | C2 | 83.33 | 104.65 | 540005.23 | CI |
| 20 | TaskD | E2 | 104.7 | H5 | 104.7 | S4 | 0.00 | C1 | 76.27 | 104.65 | 544745.93 | CI |
| 21 | TaskD | E2 | 104.7 | H3 | 104.7 | S2 | 0.00 | C4 | 681.8 | 681.82 | 3837579.55 | IC |
| 22 | TaskD | E2 | 104.7 | H3 | 104.7 | S2 | 0.00 | C3 | 97.40 | 104.65 | 610521.28 | CI |
| 23 | TaskD | E2 | 104.7 | H3 | 104.7 | S2 | 0.00 | C2 | 83.33 | 104.65 | 580302.21 | CI |
| 24 | TaskD | E2 | 104.7 | H3 | 104.7 | S2 | 0.00 | C1 | 76.27 | 104.65 | 585042.91 | CI |
| 25 | TaskD | E2 | 104.7 | H2 | 104.7 | S8 | 120.0 | C4 | 681.8 | 681.82 | 2423250.00 | IC |
| 26 | TaskD | E2 | 104.7 | H2 | 104.7 | S8 | 120.0 | C3 | 97.40 | 120.00 | 451142.40 | IC |
| 27 | TaskD | E2 | 104.7 | H2 | 104.7 | S8 | 120.0 | C2 | 83.33 | 120.00 | 416491.20 | IC |
| 28 | TaskD | E2 | 104.7 | H2 | 104.7 | S8 | 120.0 | C1 | 76.27 | 120.00 | 421927.20 | IC |
| 29 | TaskD | E2 | 104.7 | H2 | 104.7 | S7 | 78.26 | C4 | 681.8 | 681.82 | 2695786.36 | IC |
| 30 | TaskD | E2 | 104.7 | H2 | 104.7 | S7 | 78.26 | C3 | 97.40 | 104.65 | 435269.30 | CI |
| 31 | TaskD | E2 | 104.7 | H2 | 104.7 | S7 | 78.26 | C2 | 83.33 | 104.65 | 405050.23 | CI |
| 32 | TaskD | E2 | 104.7 | H2 | 104.7 | S7 | 78.26 | C1 | 76.27 | 104.65 | 409790.93 | CI |
| 33 | TaskC | E4 | 71.43 | H7 | 79.37 | S6 | 0.00 | C4 | 189.4 | 189.39 | 298026.52 | LI |
| 34 | TaskC | E4 | 71.43 | H7 | 79.37 | S6 | 0.00 | C3 | 27.06 | 79.37 | 141190.48 | LI |
| 35 | TaskC | E4 | 71.43 | H7 | 79.37 | S6 | 0.00 | C2 | 23.15 | 79.37 | 118273.02 | LI |
| 36 | TaskC | E4 | 71.43 | H7 | 79.37 | S6 | 0.00 | C1 | 21.19 | 79.37 | 121868.25 | IL |
| 37 | TaskC | E4 | 71.43 | H6 | 115.2 | S5 | 0.00 | C4 | 189.4 | 189.39 | 787482.95 | IL |
| 38 | TaskC | E4 | 71.43 | H6 | 115.2 | S5 | 0.00 | C3 | 27.06 | 115.21 | 502687.79 | IL |
| 39 | TaskC | E4 | 71.43 | H6 | 115.2 | S5 | 0.00 | C2 | 23.15 | 115.21 | 469420.51 | IL |
| 40 | TaskC | E4 | 71.43 | H6 | 115.2 | S5 | 0.00 | C1 | 21.19 | 115.21 | 474639.40 | IL |
| 41 | TaskC | E4 | 71.43 | H4 | 10.12 | S3 | 0.00 | C4 | 189.4 | 189.39 | 579833.33 | IL |
| 42 | TaskC | E4 | 71.43 | H4 | 10.12 | S3 | 0.00 | C3 | 27.06 | 71.43 | 233352.86 | IL |
| 43 | TaskC | E4 | 71.43 | H4 | 10.12 | S3 | 0.00 | C2 | 23.15 | 71.43 | 212727.14 | IL |
| 44 | TaskC | E4 | 71.43 | H4 | 10.12 | S3 | 0.00 | C1 | 21.19 | 71.43 | 215962.86 | IL |
| 45 | TaskC | E3 | 29.07 | H7 | 79.37 | S6 | 0.00 | C4 | 189.4 | 189.39 | 232198.39 | IC |
| 46 | TaskC | E3 | 29.07 | H7 | 79.37 | S6 | 0.00 | C3 | 27.06 | 79.37 | 128429.27 | IC |
| 47 | TaskC | E3 | 29.07 | H7 | 79.37 | S6 | 0.00 | C2 | 23.15 | 79.37 | 105511.81 | IC |
| 48 | TaskC | E3 | 29.07 | H7 | 79.37 | S6 | 0.00 | C1 | 21.19 | 79.37 | 109107.05 | IC |
| 49 | TaskC | E3 | 29.07 | H6 | 115.2 | S5 | 0.00 | C4 | 189.4 | 189.39 | 721654.83 | IC |

Table CIIIa Continued

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 50 | TaskC | E3 | 29.07 | H6 | 115.2 | S5 | 0.00 | C3 | 27.06 | 115.21 | 472639.84 | IC |
| 51 | TaskC | E3 | 29.07 | H6 | 115.2 | S5 | 0.00 | C2 | 23.15 | 115.21 | 439372.56 | IC |
| 52 | TaskC | E3 | 29.07 | H6 | 115.2 | S5 | 0.00 | C1 | 21.19 | 115.21 | 444591.45 | IC |
| 53 | TaskC | E3 | 29.07 | H4 | 10.12 | S3 | 0.00 | C4 | 189.4 | 189.39 | 514005.21 | IC |
| 54 | TaskC | E3 | 29.07 | H4 | 10.12 | S3 | 0.00 | C3 | 27.06 | 29.07 | 106465.41 | IC |
| 55 | TaskC | E3 | 29.07 | H4 | 10.12 | S3 | 0.00 | C2 | 23.15 | 29.07 | 98071.22 | IC |
| 56 | TaskC | E3 | 29.07 | H4 | 10.12 | S3 | 0.00 | C1 | 21.19 | 29.07 | 99388.08 | IC |
| 57 | TaskC | E2 | 29.07 | H5 | 29.07 | S4 | 0.00 | C4 | 189.4 | 189.39 | 993066.29 | IC |
| 58 | TaskC | E2 | 29.07 | H5 | 29.07 | S4 | 0.00 | C3 | 27.06 | 29.07 | 158395.64 | CI |
| 59 | TaskC | E2 | 29.07 | H5 | 29.07 | S4 | 0.00 | C2 | 23.15 | 29.07 | 150001.45 | CI |
| 60 | TaskC | E2 | 29.07 | H5 | 29.07 | S4 | 0.00 | C1 | 21.19 | 29.07 | 151318.31 | CI |
| 61 | TaskC | E2 | 29.07 | H3 | 29.07 | S2 | 0.00 | C4 | 189.4 | 189.39 | 1065994.32 | IC |
| 62 | TaskC | E2 | 29.07 | H3 | 29.07 | S2 | 0.00 | C3 | 27.06 | 29.07 | 169589.24 | CI |
| 63 | TaskC | E2 | 29.07 | H3 | 29.07 | S2 | 0.00 | C2 | 23.15 | 29.07 | 161195.06 | CI |
| 64 | TaskC | E2 | 29.07 | H3 | 29.07 | S2 | 0.00 | C1 | 21.19 | 29.07 | 162511.92 | CI |
| 65 | TaskC | E2 | 29.07 | H2 | 29.07 | S8 | 33.33 | C4 | 189.4 | 189.39 | 673125.00 | IC |
| 66 | TaskC | E2 | 29.07 | H2 | 29.07 | S8 | 33.33 | C3 | 27.06 | 33.33 | 125317.33 | IC |
| 67 | TaskC | E2 | 29.07 | H2 | 29.07 | S8 | 33.33 | C2 | 23.15 | 33.33 | 115692.00 | IC |
| 68 | TaskC | E2 | 29.07 | H2 | 29.07 | S8 | 33.33 | C1 | 21.19 | 33.33 | 117202.00 | IC |
| 69 | TaskC | E2 | 29.07 | H2 | 29.07 | S7 | 21.74 | C4 | 189.4 | 189.39 | 748829.55 | IC |
| 70 | TaskC | E2 | 29.07 | H2 | 29.07 | S7 | 21.74 | C3 | 27.06 | 29.07 | 120908.14 | CI |
| 71 | TaskC | E2 | 29.07 | H2 | 29.07 | S7 | 21.74 | C2 | 23.15 | 29.07 | 112513.95 | CI |
| 72 | TaskC | E2 | 29.07 | H2 | 29.07 | S7 | 21.74 | C1 | 21.19 | 29.07 | 113830.81 | CI |
| 73 | TaskC | E1 | 108.7 | H1 | 0.00 | S1 | 0.00 | C4 | 189.4 | 189.39 | 247642.05 | IC |
| 74 | TaskC | E1 | 108.7 | H1 | 0.00 | S1 | 0.00 | C3 | 27.06 | 108.70 | 164453.26 | CI |
| 75 | TaskC | E1 | 108.7 | H1 | 0.00 | S1 | 0.00 | C2 | 23.15 | 108.70 | 133066.30 | CI |
| 76 | TaskC | E1 | 10.87 | H1 | 0.00 | S1 | 0.00 | C1 | 21.19 | 108.70 | 137990.22 | CI |

Table CIIIb: Durations and costs for the viable methods of construction for the 3 Storeyed Building Project Earthworks (SUMMARY2 database)

| Record# | JOBPART | EXCEQ | ETIME | HAULEQ | HTIME | JOBTIME | JOBCOST | CLASS |
|---|---|---|---|---|---|---|---|---|
| 1 | Job3 | E5 | 19.7 | H8 | 0.00 | 19.65 | 17249.20 | CI |
| 2 | Job2 | E4 | 25.4 | H7 | 28.25 | 28.25 | 32316.89 | LI |
| 3 | Job2 | E4 | 25.4 | H6 | 41.01 | 41.01 | 1351020.00 | IL |
| 4 | Job2 | E4 | 25.4 | H4 | 2.06 | 25.43 | 968765.00 | IL |
| 5 | Job2 | E3 | 10.3 | H7 | 28.25 | 28.25 | 9350.90 | IC |
| 6 | Job2 | E3 | 10.3 | H6 | 41.01 | 41.01 | 28101.60 | IC |
| 7 | Job2 | E3 | 10.3 | H4 | 2.06 | 10.35 | 14644.95 | IC |
| 8 | Job2 | E2 | 10.3 | H5 | 10.35 | 10.35 | 49815.27 | CI |
| 9 | Job2 | E2 | 10.3 | H3 | 10.35 | 10.35 | 53800.19 | CI |
| 10 | Job2 | E2 | 10.3 | H2 | 10.35 | 10.35 | 28767.90 | CI |
| 11 | Job2 | E1 | 38.7 | H1 | 0.00 | 38.70 | 33965.88 | CI |
| 12 | Job1 | E4 | 10.2 | H7 | 11.30 | 11.30 | 12926.76 | LI |
| 13 | Job1 | E4 | 10.2 | H6 | 16.41 | 16.41 | 540408.00 | IC |
| 14 | Job1 | E4 | 10.2 | H4 | 0.82 | 10.17 | 387506.00 | LI |
| 15 | Job1 | E3 | 4.14 | H7 | 11.30 | 11.30 | 3740.36 | IC |
| 16 | Job1 | E3 | 4.14 | H6 | 16.41 | 16.41 | 11240.64 | IC |
| 17 | Job1 | E3 | 4.14 | H4 | 0.82 | 4.14 | 5857.98 | IC |
| 18 | Job1 | E2 | 4.14 | H5 | 4.14 | 4.14 | 19926.11 | CI |
| 19 | Job1 | E2 | 4.14 | H3 | 4.14 | 4.14 | 21520.08 | CI |
| 20 | Job1 | E2 | 4.14 | H2 | 4.14 | 4.14 | 11507.16 | CI |
| 21 | Job1 | E1 | 15.5 | H1 | 0.00 | 15.48 | 13586.35 | CI |

Table CIIIc: Durations and costs for the viable methods of construction for the 3 Storeyed Building Project Concreteworks (SUMMARY4 database)

| Record# | JOBPART | MIXEQ | MTIME | HAULEQ | HTIME | JOBTIME | JOBCOST | CLASS |
|---|---|---|---|---|---|---|---|---|
| 1 | JobD | CM2 | 61.34 | CH4 | 163.6 | 163.57 | 311958.52 | CI |
| 2 | JobD | CM2 | 61.34 | CH3 | 60.26 | 61.34 | 101336.79 | IL |
| 3 | JobD | CM2 | 61.34 | CH2 | 31.23 | 61.34 | 86163.29 | IC |
| 4 | JobD | CM2 | 61.34 | CH1 | 98.14 | 98.14 | 115543.59 | LI |
| 5 | JobD | CM1 | 85.87 | CH4 | 163.6 | 163.57 | 344214.81 | CI |
| 6 | JobD | CM1 | 85.87 | CH3 | 60.26 | 85.87 | 158806.06 | IL |
| 7 | JobD | CM1 | 85.87 | CH2 | 31.23 | 85.87 | 137563.16 | IC |
| 8 | JobD | CM1 | 85.87 | CH1 | 98.14 | 98.14 | 134897.36 | LI |
| 9 | JobB | CM2 | 30.36 | CH2 | 15.45 | 30.36 | 42642.68 | IC |
| 10 | JobB | CM2 | 30.36 | CH1 | 48.57 | 48.57 | 57183.14 | LI |
| 11 | JobB | CM1 | 42.50 | CH2 | 15.45 | 42.50 | 68080.75 | IC |
| 12 | JobB | CM1 | 42.50 | CH1 | 48.57 | 48.57 | 66761.43 | LI |
| 13 | JobC | CM2 | 15.18 | CH2 | 7.73 | 15.18 | 21321.34 | IC |
| 14 | JobC | CM2 | 15.18 | CH1 | 24.29 | 24.29 | 28591.57 | LI |
| 15 | JobC | CM1 | 21.25 | CH2 | 7.73 | 21.25 | 34040.37 | IC |
| 16 | JobC | CM1 | 21.25 | CH1 | 24.29 | 24.29 | 33380.71 | LI |
| 17 | JobA | CM2 | 7.68 | CH2 | 3.91 | 7.68 | 10786.09 | IC |
| 18 | JobA | CM2 | 7.68 | CH1 | 12.29 | 12.29 | 14463.97 | LI |
| 19 | JobA | CM1 | 10.75 | CH2 | 3.91 | 10.75 | 17220.42 | IC |
| 20 | JobA | CM1 | 10.75 | CH1 | 12.29 | 12.29 | 16886.71 | LI |

Table CIIId: Durations and costs for the viable methods of construction for the Oxidation Ponds Project Earthworks
(SUMMARY3 database)

| Record# | JOBPART | EXCEQ | ETIME | HAULEQ | HTIME | JOBTIME | JOBCOST | CLASS |
|---|---|---|---|---|---|---|---|---|
| 1 | Task2 | E4 | 133 | H7 | 130.7 | 133.33 | 653600.00 | LI |
| 2 | Task2 | E4 | 133 | H6 | 714.5 | 714.54 | 4458885.32 | IL |
| 3 | Task2 | E4 | 133 | H4 | 33.00 | 133.33 | 920432.00 | IL |
| 4 | Task2 | E3 | 77.5 | H7 | 130.7 | 130.72 | 574720.79 | IC |
| 5 | Task2 | E3 | 77.5 | H6 | 714.5 | 714.54 | 3186061.82 | IC |
| 6 | Task2 | E3 | 77.5 | H4 | 33.00 | 77.52 | 579034.88 | IC |
| 7 | Task2 | E2 | 77.5 | H5 | 77.52 | 77.52 | 1119444.19 | CI |
| 8 | Task2 | E2 | 77.5 | H3 | 77.52 | 77.52 | 1208993.02 | CI |
| 9 | Task2 | E2 | 77.5 | H2 | 77.52 | 77.52 | 646469.77 | CI |
| 10 | Task2 | E1 | 289 | H1 | 0.00 | 289.86 | 763278.26 | CI |
| 11 | Task3 | E4 | 52.9 | H6 | 400.6 | 400.61 | 2499865.95 | IL |
| 12 | Task3 | E4 | 52.9 | H4 | 63.00 | 63.00 | 434886.03 | IL |
| 13 | Task3 | E3 | 30.7 | H6 | 400.6 | 400.61 | 1752772.19 | IC |
| 14 | Task3 | E3 | 30.7 | H4 | 63.00 | 63.00 | 385629.42 | IC |
| 15 | Task3 | E2 | 30.7 | H5 | 30.74 | 30.74 | 443971.56 | CI |
| 16 | Task3 | E2 | 30.7 | H3 | 30.74 | 30.74 | 479486.63 | CI |
| 17 | Task3 | E2 | 30.7 | H2 | 30.74 | 30.74 | 256389.91 | CI |
| 18 | Task1 | E5 | 27.2 | H6 | 185.0 | 185.03 | 1154651.10 | IL |
| 19 | Task1 | E5 | 27.2 | H4 | 26.92 | 27.20 | 187768.13 | IL |
| 20 | Task1 | E3 | 15.8 | H6 | 185.0 | 185.03 | 813828.84 | IC |
| 21 | Task1 | E3 | 15.8 | H4 | 26.92 | 26.92 | 171834.78 | IC |
| 22 | Task1 | E2 | 15.8 | H5 | 15.81 | 15.81 | 228366.61 | CI |
| 23 | Task1 | E2 | 15.8 | H3 | 15.81 | 15.81 | 246634.58 | CI |
| 24 | Task1 | E2 | 15.8 | H2 | 15.81 | 15.81 | 131879.83 | CI |

Table CIIIe: Durations and costs for the viable methods of construction for the Oxidation Ponds Project Concreteworks (SUMMARY5 database)

| Record# | JOBPART | MIXEQ | MTIME | HAULEQ | HTIME | JOBTIME | JOBCOST | CLASS |
|---|---|---|---|---|---|---|---|---|
| 1 | JobA | CM2 | 71.7 | CH2 | 36.50 | 71.70 | 100712.00 | CI |
| 2 | JobA | CM2 | 71.7 | CH1 | 114.7 | 114.71 | 135053.10 | LI |
| 3 | JobA | CM1 | 100 | CH2 | 36.50 | 100.37 | 160790.70 | CI |
| 4 | JobA | CM1 | 100 | CH1 | 114.7 | 114.71 | 157674.80 | LI |

Classn:

SELECTION OF THE MOST APPROPRIATE METHOD OF CONSTRUCTION

M.G. Kagiri

ABSTRACT: A method of analysing costs and durations of alternative construction methods is presented. The method involves the use of database computer programs. Three projects have been analysed using data from Kenya. The resulting accurate and fast assessment of the relative merits of alternative construction methods enables selection of the most appropriate method.

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Master of Engineering Thesis, 1990.